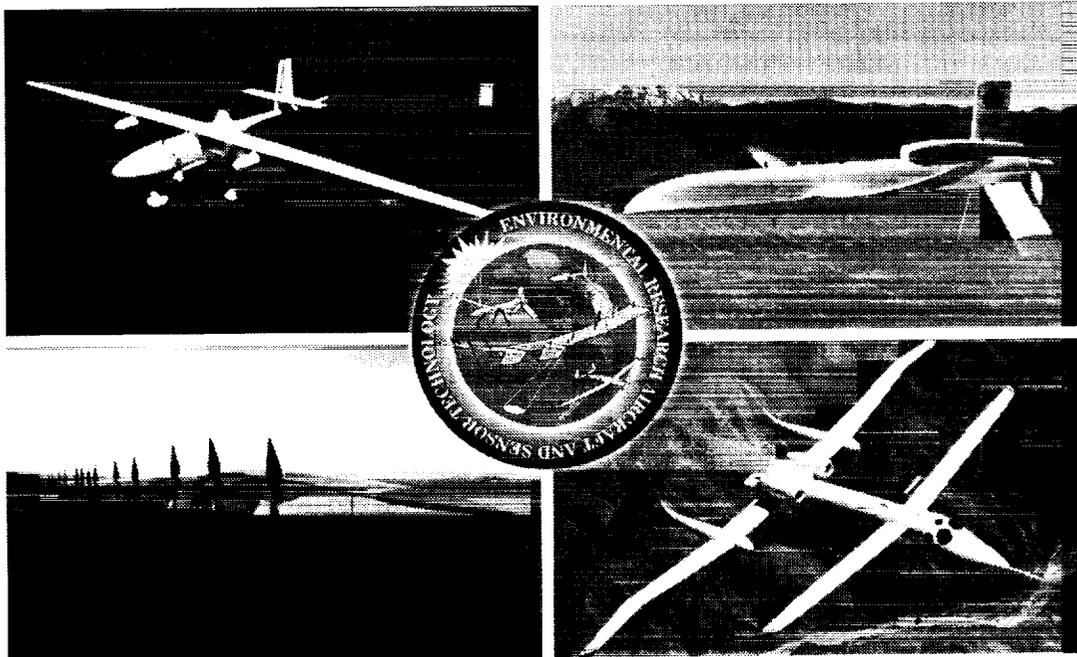


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# ERAST: Scientific Applications and Technology Commercialization

*Compiled by  
John D. Hunley and Yvonne Kellogg  
NASA Dryden Flight Research Center  
Edwards, California*



Proceedings of addresses, sessions,  
and workshops of the NASA ERAST  
Exclusive Preview sponsored by  
NASA Dryden Flight Research Center,  
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October 13, 1999

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September 2000

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# **ERAST: Scientific Applications and Technology Commercialization**

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National Aeronautics and  
Space Administration

Dryden Flight Research Center  
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# **OPENING REMARKS ON RAMP AND FLIGHT NARRATION**

## OPENING REMARKS ON RAMP AND FLIGHT NARRATION

John Sharkey: I'm the ERAST Project Manager here at NASA-Dryden. I want to welcome all of you out here for a very nice morning for flight testing. You can tell with the sun rising why the AeroVironment guys named their aircraft Helios. It's a perfect timing, perfect setting for the demonstration today. Looks like a good crowd here. We're going to spend just a few minutes getting you oriented for the day's activities with a welcome address from Kevin Petersen, our Center Director—some other opening remarks, and then we'll turn [it] over to Ray Morgan. So I'd like to introduce you right now to our Center Director, Mr. Kevin Petersen.

Kevin Petersen: Thank you, John. And welcome, everybody, here this morning. Welcome to the Dryden Flight Research Center. I know it's a very early start for everybody, but you see the kind of mornings that we have here out on the desert this time of year—it's great! We have a lot we'd like to show you today during the NASA exclusive preview of ERAST. ERAST stands for Environmental Research Aircraft and Sensor Technology. And you'll see the progress we've made in these exciting aircraft developments today. Thanks for making a special effort to be here for the kickoff this morning. This will be a very full day of events—a day full of flight demonstrations early this morning followed by static displays and workshops this afternoon. I think you'll be very glad that you took the time to come out today. One of the ideas that we hope you'll go away with is just how mature this unique class of aircraft has become in 5 short years. This NASA program was initiated about 5 years ago. We think this is good news for those who would like to explore commercial applications of this technology. It's also good news for the science community because it provides an exciting new class of research platforms and new capabilities for carrying a new class of experiments.

The aircraft you'll see here today have amassed a combined total of about 100 flights. These are the prototype vehicles for the new industry, the civilian UAV or unpiloted aerial vehicle industry. They are a result of a new way of doing business, too. A true partnership, and it's called the JSRA (Joint Sponsored Research Agreement) between NASA and our industry partners. Another part of this new way of doing business is for us to invite you out here to show you the results. We could tell you about the results at symposiums in various forms, but I think the best way is to show you the results, and that's what we intend to do today.

Our partners here today are AeroVironment, Inc., builder of the solar-powered Pathfinder Plus and Helios prototype flying wing aircraft. The Helios is the aircraft behind us here that we'll see in a flight demonstration shortly. Aurora Flight Sciences is the developer of the Perseus B. That aircraft will be on display for you to see today. General Atomics Aeronautical Systems is the manufacturer of the Altus 2, also on display later on this morning. Scaled Composites is the builder of the Proteus airplane, which will also conduct a flight demonstration this morning after the Helios demonstration is over. It's a very unique group of aircraft. I think you'll see as you view the aircraft today just how unique they are. It's a very prestigious group. These companies represent the world's premiere companies for civilian UAV technology. But don't take my word for it. Talk to the folks today. They're here to talk with you and show you what these aircraft can do. You have the opportunity to check them all out for yourselves as you go through today's events.

Shortly, you'll see the Helios aircraft take off from the lakebed for a flight demonstration. It's a truly remarkable aircraft, and I think you'll all see just what the capabilities of the aircraft are. Then the Proteus aircraft will conduct its flight demonstration. Then later on this morning, you'll be able to see these aircraft and the Altus 2 and the Perseus B over in our hangar not too far from here. You'll be able to talk to the designers and the developers and the operators of these aircraft. Then later on today, we'll hold

discussions on the science and the commercialization opportunities for these aircraft, and I think you'll be amazed at the possibilities. So I'm really looking forward to a great day. I hope all of you will have a great day and enjoy the ERAST preview events today. Let me turn it over to Ray Morgan to initiate some of the Helios events. Thank you.

John Sharkey: I'll get Ray up here in just a minute. Because he's going to script the flight and talk you through it, and narrate the event that's going to come up. I did want to follow up on some of Kevin's points here. These are prototype vehicles you're going to see today. But they also represent a class of vehicles that's ready to do business. And that's one of our themes of the gathering today. So even though these vehicles are in the flight test phase, they have started doing productive work already. So I would like to encourage you to have discussions along those lines today with the companies.

Now we wish we could have demonstrated all four or five of the vehicles for you today. But the flight demonstrations themselves would have taken the whole day—you guys standing outside in the sun. It does get hot in the desert later today. So we really just picked two of the vehicles to do demonstrations for you. They're representative of the capabilities of all the vehicles, but we're trying to keep it manageable. We want you to participate in the workshop and have exchange with the companies. So we just have two of the vehicles this morning. Now when we go to do the flight test here, I want to just try to make sure we stay confined to this area here in the front. Don't go beyond the curve right here. We'll have very good viewing of the Helios—the flight tests will be out in this area right here [points]. So if you can just keep constrained and stay in this area, I'll turn it over now to Ray Morgan, and he'll get us started with the Helios flight. Ray Morgan is the Vice President of AeroVironment down in the Simi Valley, the manufacturer, design developers of the Helios.

Ray Morgan: Thank you, Kevin and John. Thank you very much.

The aircraft you see on the lakebed out here, as you were told, is called Helios. It's our prototype solar powered aircraft. It's intended to fly up to 100,000 feet. That's above 99 percent of the earth's atmosphere. And ultimately it's intended to stay in the stratosphere for months at a time and act as an 11-mile-high tower, we like to call it. The flight demonstration that you're about to see will perhaps be startling, initially, but, I guarantee you, it's going to be the most boring 20 minutes you've ever spent at an air show... and that's part of what I want to show you. This is not risky.

We're very pleased to demonstrate our confidence in this aircraft, and we want to show you that it has a very unique, slow, and stable flight characteristic. And, this is particularly good for trying to create a tower in the sky, because that means we can fly in fairly tight circles and be, essentially, a geo-stationary platform in the sky—and that has lots of potential application.

Also, to add excitement as much as we can ... you won't be able to tell this from looking at it—but trust me, we're really going to do this ... we'll be demonstrating one of the features that makes this, perhaps, the most reliable aircraft ever designed and built. We are going to lock all the control surfaces and control the airplane on all axes using just differential motor control. So, we'll be controlling our turning, and we'll be controlling our air speed and our pitch attitude, completely, using only differential motor control.

John Sharkey: Thanks, Ray. I did forget one point I wanted to tell you about doing the flight demonstrations. All these vehicles we have in ERAST are designed for extremely high altitudes and long durations. That's real hard for us to demonstrate for you. Your necks would get tired of looking up at 65,000 feet for eight hours. So the demonstration we're going to do for you today really is just to give you

a little flavor of the aircraft and how they handle. But they really don't demonstrate the true design capabilities of the vehicles. That's going to come later on today at the workshops and the presentations.

I do believe we're getting closer now to our planned takeoff. That's one thing I compliment the AeroVironment guys on—they script the stuff out in advance. They've been out here since 3:30 in the morning trying to conduct this. They're going to go per schedule. So I believe now we're 30 seconds to go, and we'll get Ray back up here.

Ray Morgan: I'm going to go ahead and start to chat a little more. This is a remotely piloted airplane, or an unpiloted air vehicle. There are all sorts of acronyms that go with these kinds of airplanes. Even though there's no pilot on board, we do have a pilot. If you look out there you can see that funny looking little van, with the appendage on top, behind the airplane. We call that our mobile ground station. During these tests here on the lakebed we use that to go behind the airplane during takeoff and landing. That's where the pilot resides. We also have a mobile engineer who sits beside him and a mobile director who's calling the shots for the flight. You'll see those guys trailing behind them during this flight, but that's not a normal thing. When we take off we'll use the mobile station, but then it really switches to a remote ground station, and we go park the mobile van and the airplane flies mostly autonomously during the flight. I'm going to check to see how we're doing on time here; 7:26 and 45 seconds, and they're going to take off at 7:30 a.m.

What will happen next is just like a regular airplane with the pilot sitting in it. The pilot is going to call the tower and get clearance to take off. Once he does, he'll advance the throttle.

We just recently expanded the span of this airplane by about 40 feet. It's now 247 feet. We're doing this low-altitude series of tests in this configuration—with batteries—instead of with solar cells installed on the wing.

Later on when we go back in the hangar, you'll see our Pathfinder Plus airplane sitting there. That does have the solar array on it. That airplane has flown to 80,000 feet. You'll get a feel from looking at that aircraft what it would look like with the solar array on it. But right now we're flying under battery power.

The pilot will use about 70 percent of his maximum power available to take off. It will still be a fairly short takeoff roll. During that takeoff roll he will manually steer the airplane. As soon as the airplane breaks the ground, then he will switch to one of several automatic modes available. We can go all the way up to where the airplane can fly itself completely autonomously with no input from anyone on the ground. Then we have several layers back below that we can revert to where we have varying amounts of control over the airplane, down to where there's no automatic damping whatsoever.

We will be installing solar cells over the next year on this airplane. We will be putting in two different types of cells—one [with] fairly high efficiency and one a little less efficient. But with that configuration we should be able to do both missions—both the 100,000-foot mission and one to demonstrate multi-day flight.

When we go to demonstrate the multi-day flight, we'll be adding an energy storage system to the airplane. That energy storage system will store about two-thirds of the power that we collect during the day, and we'll get about half of that back during nighttime flying. That allows us to maintain our altitude at around 50,000 to 60,000 feet for days at a time.

They just called for clearing the airplane. You see the ground handlers out there move away from the airplane. The pilot will be calling the tower here shortly for clearance. And he's throttling-up to begin the takeoff roll. It flies at about 20 miles per hour at sea level. It will be flying at about 200 miles per hour at 100,000 feet because the air is 100 times less dense. You can see the wingtips lift up. You'll see the outward landing gear start to lift off first. It gradually works its way into the most inboard landing gear still rolling, and then it's off.

Now actually, we have a lot of people monitoring a lot of things during this phase of the operation, but the airplane can literally take off by itself. You can advance the throttle and let it go and it's perfectly stable. They're going to begin some turn investigations now. One of the things they'll be doing, will be investigating how fast we can turn the airplane. Because of its very large span and its very slow speed of flight, one of the issues we worry about with these configurations is making sure we can still maneuver this airplane for landing approach and takeoff. Because when you get a wing so long, once you start turning at a standard rate, there is a significant difference in speed between the tips of the plane. We've already demonstrated up to standard rate turns in this plane, and we think there's not going to be any problem. In fact, we think we can fly an airplane with an even larger span if we needed to.

One of the things about solar power is that it offers some unique capability for flying in the stratosphere. The first thing is, that the higher we go, the brighter the sun—so the more power there is available. This is opposite to air breathing engines, which depend on oxygen. As the air gets thinner they have less power to get higher. Another advantage is that the energy from the sun is virtually unlimited. Once we can store enough to get past that first night, then we have the capability of flying, limited only by the reliability of the systems.

He's starting a right turn. He's starting at 2 degrees per second. He'll be increasing that up to about 3 degrees per second, which, as I mentioned, is the standard rate turn. If we turn at these rates at about 60,000 feet, that will keep the Helios well within a 2,000-foot turning radius.

One of the main benefits of reliability is cost. It's a very low-cost way to fly. If your airplane is reliable, you do less maintenance on it. In our case, the more reliable it is—the longer we can fly. Since our fuel cost is relatively low, we have a tremendous advantage for low-cost operation.

The reliability for the Helios is achieved in two ways—the first one is simplicity. We like to call that the ultimate sophistication. The second one is redundancy. Much of these two attributes you can see just by looking at the airplane. It's simply a flying wing. As you can tell, it has a lot of motors and propellers. Each of the motor pylons takes about two horsepower and turns it into ten pounds of thrust. Each of those, in fact, only has one moving part in the pylon. There are no motor brushes. There's no gear box. There's no active cooling system and there're no radiators to leak. There's no mechanism for variation in the propeller pitch required. We can just have the motors spin faster or slower as we go faster or slower. In fact, the throttle is controlled completely electronically and with all solid-state components.

The flight control system also uses nearly all solid-state sensors. All the critical flight sensors are triply redundant. In fact, the design principle for all these series of unmanned airplanes has been that any failure required no immediate action and you could return safely home.

You know, even though we use differential thrust to turn the airplane, we can still allow multiple motors to fail and adequately control the airplane. We're currently using elevators on the trailing edge as our only moving control surface, but we have 72 elevators that are independently actuated. We could lose

a dozen of them and still operate normally. Not only that, but, we'll be demonstrating in a few minutes a mode where we don't even need those elevators. We'll be using the difference in the thrust between the high motors on the tips of the wing and the low motors in the center of the wing. We'll use those differentially to control the pitch of the airplane and thereby its air speed. This means we could throw all 72 elevators away. So there we've achieved another level of simplicity and another level of reliability.

We've been demonstrating since 1995, a self-test system that allows the autopilot to determine if any part of the flight-control system is degrading for whatever reason. It doesn't need to know why. And it will allow the flight-control system to reconfigure itself—reconfigure the control laws so it will be tolerant of a failure of any part of the system.

To describe this to you in layman's terms, if you've ever owned an old car with worn ball joints or, even worse yet, worn kingpin joints, you know that when you're driving straight you have to slam the steering wheel back and forth to keep it going straight. Well, the autopilot can account for that. If the hinges are wearing or something's going wrong with the system, it can account for that and reconfigure itself so it takes a new set of gains and does the equivalent of slamming the steering wheel back and forth with worn ball joints.

I told you this was going to be boring, right? So nobody should be disappointed. The real exciting part is just minutes away though. Because Wyatt, our pilot, will be doing some checks as he comes out of the next turn. And he'll be ready to go into the M-mode. That means all the elevators are locked out. At that point we'll be using strictly differential thrust to control the airplane. If you can tell that they're doing that, you're better than I am.

Well, what value does this airplane have? If you're a scientist, imagine that you could monitor the tropopause persistently over a site, not just for hours or weeks but months at a time. If you're a meteorologist or an insurance actuary or a farmer or a commodity speculator, imagine if you could have an airplane loiter off the west coast of Africa watching storms come across, waiting to see if one of them organizes into a hurricane, and then being able to continuously stay with that hurricane and track it as it moved across the Atlantic. You could continuously take measurements, drop dropsondes into it, sense the effluence out of it, do all the things that allow the meteorologist to have a much more accurate prediction of its strength and path.

In fact, I recently met with a Naval meteorologist. He told me that the Navy today can predict, 24 hours in advance, the path of a cyclone only within 110 miles, and that has not improved in the last decade. The main reason is that they cannot get a fix on the center of a cyclone within 50 miles using satellite information. Until it's developed to a full-fledged hurricane with a developed eye they can see from above, they have to have something they can get in to sense the rotation so as to figure out where it is. If they could do something like this, they could immediately cut the error band of that prediction in half.

Imagine if you're a disaster relief organization and a massive hurricane destroys a country in Latin America. You can't find out the condition of its seaports, its runways, its highways or its cities. Communication is wiped out. You can't get approval to fly in a military airplane. Imagine that you could launch one of these beauties, here, from the United States—continental United States—fly down and stay over the Latin American country, provide all the geographical information you need remotely, and at the same time even provide communication relays for the people there—the relief teams. A gentleman from the State Department, Mr. Larry Roeder, will be speaking at the conference later today and talking about these sorts of operations.

However, the really big payoff for this type of system is in telecommunications. NASA, in its wisdom, created the Environmental Research Aircraft and Sensor Technology program not only to provide scientific research vehicles, but to kick-start a commercial U.S. industry for these remotely piloted airplanes.

I've got the word the aircraft is in an M-mode now.... Let's see if we can tell.... They'll be landing in just a few minutes.

We believe that the Helios is ideally suited as a low-cost, rapidly deployable platform for broadband and other telecommunications applications. We also think that it could be used to overcome the last mile barriers that face conventional, terrestrial and space-based approaches. As I said earlier, because of its slow flight, we can act pretty much like an 11-mile-tall tower.

One of the advantages also is that we can provide local frequency re-use. Because we are acting like a tower, we can provide aimed antennas that use the same frequency over and over and get much more use from the spectrum. Due to the lower altitude of Helios versus space satellites—we are at 11 miles up instead of 400 or even 25,000 miles for geo-stationary satellites—less power is required for transmitting and receiving. Smaller and lower cost communications equipment can be used, and network performance can then be improved. There's also much less latency in the transmission because it doesn't have to travel the distances.

The really unique aspect of a stratospheric-platform approach is that you could rapidly deploy this system and provide an immediate coverage for a target area. You don't have to deploy a full constellation of satellites, for example, to bring in your first customer. You can go into one market at a time. You can expand that market. You can relocate it, and you can maintain it. You can upgrade the system.

Another real advantage is that you don't have to space-qualify your hardware. The equipment that you have to put on the satellite—just because you've got to be sure it's going to last 10 or 15 years—you have to put through perhaps 5 years of qualification. That means you're freezing your technology 5 years before you launch it. With a system that you can put up into the stratosphere like these remotely piloted aircraft, if you have a problem with your payload, you can bring it back down and repair it or you can upgrade it. Every six months you can have the latest state of the art. If you look at the difference in desktop computers from now and five years ago, you get a feel for what that means. You can use the latest technology at the lowest possible cost and the best performance.

They'll be landing to the south, right down here in front of the ramp. Do I have any questions?

Question: How much power do I expect to be available to support a science payload?

Ray Morgan: We're nominally aiming at one kilowatt and 100 kilograms for the Helios. But that's flexible, depending on how we configure the airplane and the mission itself—where the mission will take place, and things of that nature. So it's variable. But on the average of one kilowatt is what we're planning.

Question: What would it cost per unit if you produced thousands of these things?

Ray Morgan: We expect the production price of the Helios to be on the order of 3–5 million—depending on the solar array, which will dominate the purchase price of the airplane. Hopefully it will be around 3 million. It could be higher. But that's our estimate right now, as best we know it.

Question: Would the one kilowatt be the maximum amount of power available?

Ray Morgan: No. The one kilowatt would be an around-the-clock average. You could have peaks much higher than that. We have up to 40 kilowatts available from the array. For momentary pulses, you could conceivably give the whole 40 kilowatts to the payload.

Question: What is the wind and turbulence envelope for takeoff and landing?

Ray Morgan: That's a very good question, because obviously this is a slow flyer. You can ride your bicycle faster than this airplane flies near the ground. And, therefore, we don't take off in strong winds. And we try not to land in strong winds. Our rule of thumb is that we don't fly with the winds near the ground over 10 knots at takeoff and landing. However, we have landed in 26-knot winds. There were 26 knots at 500 feet, and we actually flew the landing approach backwards. We landed perfectly okay on an island in Hawaii with no problem whatsoever. It's all in how we plan it. We use a device called a SODAR, which our company also makes. It is in a box. And that device will give us the wind vector, over time, up to about 4,000 feet above the ground. We include that in our planning.

Do we see it here? It's by the edge of the lakebed over there.

But the fact of the matter is that we plan when we launch and recover. When we're flying just a daytime mission, we launch in the morning. We recover about midnight. Both of those times are in the diurnal cycle where the winds have died down and the turbulence is low. We also characterize the area we fly from, and we do that as part of our planning process. Once we get to the Helios where we stay up for six months at a time, we could launch from—say Las Cruces, New Mexico—and service the world. I mean if you can stay up six months, it doesn't matter if you take a week to get over there. So you really have a true hub capability. And when you're staying up six months, you can choose whether you land this week or next week, so you can avoid any bad weather that comes in. The fact that you're flying for such a long time—and you have the capability to fly even after something is broken so you can stay up until you can bring it back—it enhances the ability to get around any weather limitations of the system.

He's down. He landed back behind the guys. He landed pretty much right on schedule—maybe one minute late.

Thank you very much on behalf of the crew.

Any other questions?

Question: What are the stall speed and cruise speed?

Ray Morgan: I know it in feet per second. So if you can divide by 1.47 you can get it in miles per hour. It stalls at about 27 feet per second. Cruise speed is around 32 feet per second. Maximum speed is a little over 40 feet per second at sea level.

Question: What is the maximum speed at cruise altitude?

Ray Morgan: If we're at 60,000 feet, it's about three and a half times what it is at sea level.

You'll see a dolly be brought up next to the airplane now. This dolly is much like a boat trailer, except that we have wheels that we can let it move in whatever direction we want to. It's towed behind another vehicle that has a great big funny-looking fence on it, that's a wind fence—same thing they put around tennis courts. That helps shield it from the wind while we're towing it. We have ramps we drop down. The ground crew will roll the airplane up on the ramps and onto the dolly, then will lock it in place. After it's on that dolly it's quite secure. We can tolerate very high winds in that condition while we're taking it back to the hangar. Right now, for this display we're in a large hangar that allows us to put the full

247 feet into it all in one piece. Normally when we fly here we're flying from a hangar that's not that large, and we actually have a quick disconnect joint in the center of the airplane. We roll the airplane up to the front of the hangar. Then we disconnect the halves and bring it into the hangar in two halves. When we go to fly again, we roll it out, and, in 15 or 20 minutes, hook it together, and then go fly. It's the same thing. Therefore, we can actually operate in quite small hangars. And we have operated in Hawaii with a portable hangar for a couple of years. That worked just fine. It's quite small. Because it's only long in one dimension ... so it's like a long string ... you can put a lot of them in a small space.

Question: What is the payload at 60,000 feet?

Ray Morgan: The payload at 60,000 feet would be on the order of 100 kilograms for the Helios prototype. We have flown as much as 600 pounds, a little less than 300 kilograms, on this structure—and it's a performance trade. When we put more weight on there, we could trade off how high we go or whether we stay up there continuously day or night, or what latitudes we fly at to carry more weight, if we need to. And for a day mission—the 100,000-foot type mission—if we wanted to load it up, we could still get 600 pounds to about 80,000 feet for awhile.

Question: What is the maximum latitude of operation?

Ray Morgan: In the summertime we can go right up to the pole. In the wintertime, it depends on the cell efficiency we're flying, mainly. And with the cells that we expect to be available in three years, we're looking at nominally about a 25-degree maximum wintertime latitude for continuous operations. But that's expected also to increase gradually, and within ten years we expect to be able to cover most of the U.S.

Nick Colella: Do you have any plans for satellite links?

Ray Morgan: We don't—for commercial operation. Certainly satellite links could be a piece of what we could do, both to expand the footprint of a satellite—help punch through with a different frequency if the satellite's coming down at a high frequency. Because of bandwidth, we can reconvert that and punch it through at a lower frequency, through the rain. We don't have specific plans in place right now for a specific type of satellite link, though.

Question: While you're flying it, what does it cost for the ground crew?

Ray Morgan: Once we're deployed with a system, we expect to be able to operate up to ten aircraft with one pilot monitoring them. Because they're up there like satellites—up there for a very long period of time. They're completely autonomous. All we need to do is an occasional health check. So we're forecasting that one pilot could actually operate up to ten aircraft at a time. We would have a ground crew that would be there when they're cycling the airplanes up and down.

Well, we have about half an hour before the Proteus will be flying. I want to thank all of you very much for coming out to see this boring exhibition. If you have any questions—you see any of us walking around here with funny caps and the green shirt, we're part of the AeroVironment team with the added individual of my boss, Tim Conner, who's in the brown coat right over here. Feel free to ask us any questions.

John Sharkey: Thank you, Ray. To set the stage for the Proteus flights, I want to introduce Bob Waldmiller.

Bob Waldmiller: Good morning. In a few minutes you'll see the Proteus aircraft. I'll give you a little introduction on it before we start the flight demonstration. The Proteus is a unique aircraft, designed as a high-altitude, long-duration telecommunications relay platform with potential for use on atmospheric-

sampling and earth-monitoring science missions. It was designed by famed aircraft designer Burt Rutan and built by Scaled Composites in Mojave, California. Normally flown by two pilots in a pressurized cabin, the Proteus also has the potential to perform its missions semi-autonomously or flown remotely from the ground. Burt Rutan initially designed the Proteus to carry an 18-foot-diameter telecommunications antenna system for relay of broad-band data over major cities. His design allows Proteus, so named for the mythical Greek sea god who could change his appearance at will, to be reconfigured for a variety of other missions such as atmospheric research, reconnaissance, surveillance, commercial imaging, and launch of small space satellites.

The aircraft is designed for extreme reliability and low operating costs, and to operate out of general aviation airports with minimal support. It is designed to structural load requirements of Part 23 of the Federal Air Regulations for general aviation aircraft weighing 12,500 pounds or less. Proteus features an unconventional-tandem-wing, twin-boom configuration, with two rear mounted turbofan engines providing power.

The aircraft features modular construction, including a removable center fuselage barrel that can carry payload internally or externally in an underbelly pod. Removable tip sections can be added or removed from the wings to tailor the aerodynamics for various external payloads or for maximum altitude. The main landing gear is set wide apart, allowing for large, externally mounted payloads to be carried underneath the fuselage. In addition, smaller payloads can be carried in a variety of locations throughout the aircraft.

In a few minutes Proteus will be passing through, and we'll start our air show demonstration. It will be beginning from the south, which is to your right, and I'll start the narration at that time. When we're ready to go, the crew will maneuver the airplane to a position in front of us and initiate a maximum performance climb.

To achieve its objective of high-altitude flight for long durations, Proteus must climb quickly to the desired altitude. In its typical mission configuration, Proteus is capable of achieving an initial rate of climb of over 6,000 feet per minute. The aircraft set two milestones on its 16th flight in February 1999, when it reached an altitude of 50,000 feet while carrying the operating science imaging payload the Airborne Real-Time Imaging System known as ARTIS.

The small ARTIS camera was developed by HyperSpectral Sciences under NASA's ERAST Project. It was operated remotely by the flight crew taking visual and near infrared photos of the California desert near the Mojave Airport. The system mounted in NASA's designed pod beneath the Proteus fuselage was later used to take similar near real-time images over Oshkosh, Wisconsin, during the Experimental Aircraft Association's Air Venture 99 Air Show, with the images displayed on a computer monitor at the show only moments after they were taken.

Equally important with Proteus' climb performance is its descent performance. The ability to return from high altitudes quickly, means the ability to turn the airplane around for another mission. Being a slow-speed airplane, to achieve its mission objectives Proteus has an operational speed limit of 160 knots, or Mach 0.6 at high altitudes. In the configuration being flown today the limit is 140 knots, or 0.55 Mach at altitude.

Originally intended for long-duration loiter missions in support of its telecommunications role, Proteus was designed to fly in a relatively small volume of airspace and at slow speeds. If Proteus were to

loiter for an extended period of time, it would be flying at 90 to 110 knots. At those speeds the aircraft could remain aloft for 12 to 14 hours. Let's watch, as Proteus completes a typical loiter maneuver.

Somewhat unique among other manned, high-flying airplanes, Proteus is flown without pressure suits. In many ways, the Proteus crew cabin is designed more like a space vehicle than an airplane. In that context, the crew works in a very comfortable shirt sleeve environment, much like the environment on a space shuttle.

Proteus is being flown today by two of Scaled Composites' most experienced flight crew. The pilot, Doug Shane, has flown the majority of aircraft produced by Scaled Composites, including a previous ERAST airplane known as the Raptor. In the right seat is Pete Seebold. Pete developed most of the autopilot software under the ERAST Program in this airplane. In addition, Pete flew with Mike Melville to Paris, France, in the very same airplane being flown today. They crossed the Atlantic twice non-stop. With the ability to operate out of most general aviation airports, Proteus is very neighborly. During this slow speed fly-by, notice how quiet Proteus sounds.

The flight crew will now conclude the flight demonstration and return for landing on the main base runway at Edwards Air Force Base. In a short while, Proteus will return to the area for further viewing. And we can field the questions at this time, to which I'll refer to Burt Rutan, who is somewhere in this crowd. I'll now turn over the mike to the legendary Burt Rutan.

Burt Rutan: Proteus was developed to perform multiple missions. In addition to telecommunications, we're looking at using Proteus for airborne early warning as well as reconnaissance. We are presently working several programs at the concept design level that involve using the Proteus airplane to launch rockets, both manned and unmanned.

Relative to the flight demo you are about to see, I apologize that you will not see the takeoff from our vantage point. When we practice this air show at Mojave, you get to see the airplane take off and land right in front of you. The takeoff demo is important because the airplane has a unique landing gear system. I'll describe it and that may be helpful. An airplane that has a low wing loading, which an airplane must have for good loiter capability, also is an airplane that is more subjected to the hazards of landing when you have gusty crosswinds. The normal way to solve that is to remove wing lift at touchdown by putting up spoilers. When you land on an airliner, you'll notice that the wing spoilers come up so that the airplane can plant itself more firmly on a runway. Proteus has a tricycle landing gear that is really [a] "three mains" landing gear. It doesn't roll along, rotate and then lift off like a conventional airplane. Its center of gravity is well forward of the main landing gear. So Proteus sits nose down on the landing gear. It flies off the runway at that attitude. When the pilot pulls back on the stick he deploys his canard elevator, which doubles as a full-span slotted flap on the front wing. During the takeoff roll, at a speed when the airplane can lift off in the nose-down attitude, it lifts off, and then can immediately climb. For landing, it can touchdown at a nose-up attitude. As soon as touchdown occurs, the airplane falls onto the forward main gear, and then the pilots can push the stick forward, which depresses the lift of the entire front wing such that once the airplane lands, without slowing down even a knot and without putting up any spoilers, it places the majority of the weight on the wheels instead of on the wings. That's kind of a unique design feature that allowed us to have an airplane very simple without littering the wings with spoilers, and yet able to have an airplane with a very light wing loading to go out and land in very gusty conditions. A continuous-presence mission for the telecommunications or for airborne early warning requires that the airplane must fly, even in bad conditions.

Does anyone have any questions? The ceiling with the FJ44 engines is the question. Our basic issues with the operation of the FJ44 at high altitudes are not just altitudes; they're also the lower Mach numbers. We loiter best at around 0.45 Mach number, below the normal operating speed of the engines, which is 0.5 Mach number at altitudes above 50,000 to 55,000 feet. The engines on Proteus are not standard FJ44-2s. They've been modified to have better surge margins at the lower speeds and high altitudes. We expect to be able to operate them up to about 65,000 feet. The Proteus can extend its wingtips. The airplane is structurally built to allow bolt-on wingtip extensions. When we have a need to go very high—for example, to go up and sniff ozone at higher altitudes—we can bolt wingtip extensions on the canard and the back wing and go higher than we can go without them. The Proteus airplane does have a limit, like the U-2, where the critical Mach number and stall come together. However, we don't approach that because we're thrust-limited to lower altitudes. The engines were selected for minimum operating cost for the continuous presence mission. Unlike the U-2, the airplane is underpowered so that it does not have enough thrust to get it up to the altitude where the stall speed and our critical Mach number come together. If we had more thrust we could fly it above 70,000 feet.

Answer to another question about the pod: That pod is built for Raytheon, which is working on a telecommunications payload. Currently its payload is spec'd at 1,800 pounds and 23 kilowatts for continuous use. The airplane is structurally designed to carry a lot more payload—as heavy as 6,800 pounds. However, with a 6,800-pound payload, we don't carry the full fuel load.

Question: What is the flight endurance if it's remotely piloted without a crew?

Burt Rutan: Well, the airplane can carry as much as 8,000 pounds of fuel. A flight crew of 400 pounds isn't a large percentage of that, so it's roughly the same. The airplane's telecommunication missions will be run using 5,000 pounds of fuel at up to 14 hours. The airplane can be flown as long as 20 hours, if it's flown at its best altitude and loiter speed.

Question: What is the turn radius?

Burt Rutan: You saw a relatively small turn out here at low altitude. As we go higher, we are limited to roughly the same indicated air speeds, but our true air speeds are much more. The issue on turn radius for the telecommunications mission involves what you lose in altitude capability by staying in a tighter turn, and also that is exacerbated by winds. For example, if the winds are 100 knots, the airplane has to bank as much as 30 degrees when it's in a 6- or 7-nautical-mile-diameter circle. If we bank more than that, then we put portions of the airplane in the field of view for the sensors. So we believe we'll be limited to somewhere around 6-nautical-miles-diameter for the telecommunications missions to be able to deal with the performance, which we lose by higher bank angles, and also the field-of-view that we lose by banking more steeply. The reason that the airplane is tandem-wing and the reason that it has this strange-looking aft-wing dihedral is a field-of-view-for-telecommunications design issue. A reconnaissance airplane can be designed to look only out to the side or only down. But the telecommunications requirement for the airplane as it's orbiting was that we needed to look continuously at all azimuths and the lower hemisphere up to about 10 or 15 degrees below the horizon. We had to look all the way around continuously without the airplane being in the way. That was a very difficult thing to do. It makes an airplane have to have a tall landing gear with the antenna below. And, again, when the winds are blowing 100 knots, you have to bank more. The Proteus has a relatively large dihedral for most of the span. The fuel is in that portion of the wing where the ailerons, flight controls and other systems are located. But the portion of the wing that's turned down outboard of that to give the airplane the proper aerodynamic dihedral effect—that portion has no systems, no metal—it's just very light basic structure, almost like a radome. So Proteus has a dielectric left wing and a carbon fiber graphite right wing. Where the wing makes this transition, this curve—even though that wing spar is made in one operation—the materials transition from graphite to

fiberglass. That way we have a dielectric wing that's in the way at the higher bank angles when we're looking that direction and when we're turning left.

Another question, about the turnaround time between flights: The Proteus can be turned around very much like a business jet. It has commercial-business-jet-like systems. The airplane can be pre-flighted, fueled, and turned around within an hour. In general, though, on a continuous presence mission there's a longer post-flight and pre-flight, and generally we're planning on an airplane being on the ground for at least three hours before it's turned around for another mission.

Another question about pressure suits: We plan to use pressure suits in our development. That's what's been limiting us to 50,000 feet now. We cheated a little bit. We went up to 51. But, in general, we don't plan to take the airplane up to its high-altitude capabilities until we have pressure suits. That's an item that NASA has been helping us with in terms of borrowing pressure suits. Our program right now is not funded by a large customer, and we're on a shoestring, as it were, now. We've been very appreciative of the help that we've been getting on the pressure-suit support. The airplane is not intended to have pressure suits, though, for operational missions. It needs to be a shirtsleeve environment for the continuous-presence mission when you're up there all day. You don't want to be sitting upright in a pressure suit like you are in a U-2, because the fatigue factor on those flights is just horrible. Operationally, the airplane will be operating above 50,000 feet. We just want the pressure suits the first times that we go up there until we demonstrate and prove the various failure modes of the pressurization system. We have built and tested-to-failure a pressurized cabin of Proteus that's identical to the airplane. We've shown large margins over what we would need to certify the pressure vessel. Structurally, we're in very good shape. It's just that until the first time we go up there, we're unable to test the pressurization at the flight loads and at the flight temperatures. When we go up there the first time with a flight crew, we go up to an altitude in which the crew would die if the structure fails. We want to have pressure suits when we go up there because we will be exposing the airplane not just to the pressure but also to the flight loads and the very low temperatures.

Question: Are there plans for more than one vehicle?

Burt Rutan: We have put out bids for several applications that require several airplanes. We have also bid to Angel Technologies a fixed firm price to build 100 airplanes. We're very interested in building additional small numbers of airplanes—research airplanes like this one—and we're also, of course, interested in a production run that would kick off a full certification program.

## **FORMAL ADDRESSES**

## FORMAL ADDRESSES

Victoria Regenie: Welcome to our next session on the formal addresses. My name is Vicki Regenie, and I'm the Flight Research Program Manager at the Dryden Flight Research Center.

I have the honor to introduce Mr. Rich Christiansen. He's the Director of Programs at NASA's Aerospace Technology Enterprise. He has been a major instigator in the whole ERAST Program. He was there helping it get started at the very beginning, which is one of the reasons he's speaking today. In his job as the Director for Programs, he's responsible for the strategic management of all the Enterprise programs being planned and conducted for the aeronautics and space transportation goals. He leads the Headquarters and the Center program management staff in formulation, advocacy, and assessment of basic and focused research and technology programs. These span R&D from fundamental research to flight demonstrations of advanced systems. And we go anywhere from the low-speed regime, as you've seen with the ERAST aircraft, to low-cost access-to-space vehicles.

Before he was in this job, Rich was Division Director or Program Manager in several organizations. He was also Acting Associate Administrator for the Aeronautics and Space Transportation Technology Enterprise and has received the NASA Outstanding Leadership medal. In 1998 Rich was awarded the Presidential rank of Meritorious Executive for his superior accomplishments in program management since becoming a Senior Executive Service individual. His past—He worked for the Ames Research Center conducting system analysis and large scale aerodynamic and propulsion wind-tunnel tests. Before that he came to NASA from General Dynamics, where he came from California State Polytechnic University in Pomona, California. I'd like to welcome Rich.

Rich Christiansen: Thank you, Vicki. Welcome. This is an amazing turnout. It was a great day out there. I've been supporting flight programs out here at Dryden now for about 15 years. Every time I get to come out and enjoy the opportunity of seeing a flight it kind of makes me giddy. So if you feel me wandering off a bit and sounding a little nervous, it's because today was a great day—two birds up, two birds down. Can't be better than that.

I do want to thank all of you for coming out here. There were 275 people who signed up this morning. And I think most of you are all still here. We have people from various government agencies besides NASA: many people from industry, both those who are part of the program in developing this capability to supply aircraft that can go into commercial ventures as well as people from the business end—those that would use these capabilities to create new businesses. We've also had the press there this morning and some here now. You haven't seen them, but we also have an important component of this. There are about 80 school kids here participating in a separate program that's all part of beginning to learn and enjoy the experience of flight. So perhaps sometime during the day you'll run into them. It's always been amazing to me to see the faces brighten up when they see things like we do in this program in ERAST—things that are unusual and different and unique and exciting.

I'm going to go through a little bit of introduction of why we're here today and then talk about how we got here, and in the end wrap up with some comments of where we think we may be heading in the near future.

This exclusive preview of the various remotely piloted aircraft is the work of a group of people formed under what is called the ERAST Alliance. ERAST stands for Environmental Research Aircraft and Sensor Technology. The alliance itself, again, refers to individuals both in industry and in government and from academia and all around who have formed this unique partnership to develop this

extraordinary class of aircraft that you see here today. This month, October, marks the ERAST Alliance's fifth anniversary. We've been working a great deal in the world of R&D up until today in trying to create the capabilities collaboratively so that in the end these types of aircraft can be put into useful occupations.

I was talking with Jenny Baer-Riedhardt, who helped me put this thing together all that while back. We were commenting on how this is kind of like graduation from high school for the kids. So we're all kind of excited to see this happening and interested in what's going to ever become of them. That's really what today is about. Some of the concepts are quite mature. The reason for this preview is to make sure that many of you can see the demonstrations and recognize that the fine prototypes we have here are proving that these type of capabilities are available and they're ready for business. I think it was mentioned earlier—ready for business is the theme for this event.

Many of you represent the prospective customers from many diverse fields of application that could use high-altitude aircraft as means to either replace or support conventional systems such as satellites, whether it be for telecommunications or other types of observing activities. We don't pretend to foresee all the potential uses here. But certainly I think the audience represented here will bring a lot of keen ideas, not only with regard to science but other types of commercial operations. I hope through the course of the day, going through the various sessions and forums and talking to a lot of the individuals, that each of you will actively participate, both in asking questions and seeking guidance. I hope those of you who are here providing the capabilities have got your sales cards out and ready to work from the business end.

A little bit of background: I think I talked about my participation in getting this off the ground about five years ago. But the journey to this point actually, for myself, began about ten years ago. At Headquarters we had been conducting a set of studies to look at the possibility and the market and the potential benefit of technology that had been developed over the past 20 years to see if the time was right for supersonic transports to be brought back into the picture. Of course, the experience with the SST program of the '60's and '70's showed us that environmental conditions and factors need to be considered first.

It was also during this time frame that research was being conducted by various atmospheric scientists who were beginning to find evidence that man-made emissions could effect the atmosphere on a global scale. So we really wanted to get serious about understanding what was going on and, in particular, for supersonic transports that do want to fly in the upper atmosphere or the stratosphere—because it is an area of our sky that is particularly sensitive to what goes on in it. However, in the analysis of various computer codes and trying to glean some information from satellites, we found that the uncertainty in the data did not give us a great deal of confidence to fully predict whether the effects were long-lasting or, in fact, entirely detrimental. And so the quest began to look at how do we gain better data from the higher altitudes in order to improve the codes and better validate the satellite information.

So at that time—again, this was about ten years ago—I came out to Dryden and talked to some of the folks about what we could do. And, of course, we sort of got in the car and drove down to Lockheed Skunk Works because of its heritage with U-2's and the ER-2's that were being operated by NASA's Ames Research Center just north of here. After consultation, while it looked feasible to do something that would get added altitude beyond the current capability, at the time the costs just didn't justify themselves—plus we really couldn't afford the loss or the use of any of the aircraft that we had, to do any of the modifications.

So we looked for other venues. It also turned out at the time the Defense Advanced Research Projects Agency (DARPA) was involved with Boeing developing the high-altitude, autonomous platform called Condor, and we began some dialogues with them. But even there, the costs to add the capability that we were looking at—the much higher altitudes—were a little bit out of boundaries for the benefit that we thought we would get and, in particular, since they were in the course of development, we couldn't impact their schedule. So instead, at that time, we decided to wait, let the computer models improve, and have the Earth science folks get more satellite data and get other activities going—and while they were at it, being able to use the current platforms to better improve certainly the prediction capability at lower altitudes. So we postponed that for awhile.

Then shortly after Dan Goldin arrived at NASA, a lot of things changed. We went into high gear in many places, and this was certainly no exception. I won't say that it happened overnight, but it did happen over a weekend. Dan took a great deal of interest, not only because there were folks within NASA talking to him about things that he'd asked about, where can we build some new excitement, explore new frontiers and create new capabilities—but he'd also been taking advice from many people outside of the agency. Many of you, I think, were involved in some of those early discussions.

Funding was identified. We were charged with the responsibility of creating a robotic aircraft capability that NASA could use to obtain stratospheric data. Now, all that happened very quickly. But with that decided, the most interesting debate left to us was what to call this new program. I had offered up an idea that I'd toyed with earlier—the High Altitude Research Program or HARP—had logo sketches with planes flying with angels in the sky, playing the harp and all that. For whatever reason, that idea was turned down. And after several iterations, Environmental Research Aircraft and Sensor Technology became the name. The name was important, because it added a very important idea to what we were about—that the job is not just to fly at altitude, but it's also to carry sensors to do a mission. The sensors that were available at the time were seriously overweight for what we needed to do. So the ERAST Program started off looking at both complimentary technology activities to not only create the aircraft capability but to help bring the weight of the instruments down. It was the only way we could see how we might get to our goal of 100,000 feet. You may not immediately appreciate the tremendous task of making an aircraft capable of flying in this environment where the air is very thin.

I think folks, this morning—Burt Rutan, in particular, and I know Ray Morgan can speak much more eloquently about the technical issues—about flying at these altitudes. I'll say it very simply, though, that the problems of control and propulsion at these altitudes are quite daunting. Of course, there are aircraft that do fly at those altitudes. The SR-71, for example, routinely flew at these very high altitudes. But it does it by flying very fast. At these speeds, the shock wave that's created whenever you stick a probe out to gather air samples—that shock wave actually changes the character and nature of the air you're trying to gather and basically makes the data—I won't say not useful—but it adds so much uncertainty in trying to back-calculate what the air was before it went through the shock that it didn't help improving our confidence in reducing uncertainty. So we didn't venture that way.

But not only do we have to go high; we have to go slow as well. In fact, some scientists were suggesting that we just stop. That would greatly improve our chances of gathering good samples of air. Well, going high and slow—you need either a lot of wing area for very little weight—and this morning the discussion was about, low wing-loading—or you need something that has a lot of thrust. Well, to be able to provide a lot of thrust at those altitudes you need either big engines or perhaps rockets. Well, big engines and rockets moving slowly are going to put emissions out into the very atmosphere that you're trying to get pristine measurements of. So that really wasn't a choice that we could make. The only thing

left to us was build big wings and lose a lot of weight. We thought about asking the pilots to go on some rather severe diets. But even in the end when we looked at it and counted up the pounds we felt that still wasn't feasible. So we dropped the pilots. While we did that, we added a great deal of complexity to our problem, as you might understand. Robotic aircraft still have a great deal of work in trying to make sure that—whether the autonomous part or the semi-autonomous where pilots are on the ground—flying can be feasible and very reliable. And that was something that we needed to focus on very early in the formation of the ERAST activity.

Anyway, we've got a program. We've got a name. And we've got a very serious challenge of trying to make it happen. So again, I came out to Dryden, as many of you know reading history books and whatnot—out to this site, where both NASA and the Air Force (and many others) have taken great strides in aircraft development. Altogether we asked ourselves how and who in this country can get this job done, and how can we do it in the shortest possible time frame with a quite modest budget. The list of possibilities was actually quite short.

That's when we kind of created this idea that what we really needed to do was create a kind of stratospheric dream team, pulling together a handful of brilliant experimental aircraft manufacturers that were already beginning to look at solving these problems—not with NASA but with various organizations within DoD. And so that became our challenge to create this and, in essence, go out and try to adopt the existing kids that were out there and bring them into our home. The four small businesses that were part of the effort are AeroVironment, Aurora Flight Sciences, General Atomics, and Scaled Composites. I'm sure you've read about them and you've seen the various things—whether in the press or, at least for today, certainly, to be able to go out and see in real life what they've done. This team has grown together over time since the beginning. I'll talk a little bit more about some of the specific partnerships later.

We're very proud about the accomplishments that we've made in ERAST. We've worked very hard to produce cutting-edge-technology results, whether bringing a few of the staff from within the agency to focus on particular problems and certainly within these small, highly skilled companies—bringing together the talents that they have. We think that ERAST has produced a great deal more than similarly funded programs in other agencies—in particular focusing on the unpiloted aircraft development. How did we do it? We looked at new ways of doing things. We tried to break the old barriers in strict contracting and specifying requirements. We tried to find ways of doing more with less. At the same time, we also wanted to make sure that there was something in it for the partners. The fact that we were open to promoting their potential commercial benefits for these systems was an important element.

The part about trying to design something new—something that we hadn't done before, at least on the scale of this program—it took a great leap of faith and a lot of visionary management to try to explore new ways of doing business, new regulations, new rules for how we would operate UAVs and new ways for actually conducting business. Jenny, whom I mentioned earlier was the first Program Manager here at Dryden. I give her a great deal of credit, and also a great deal of credit to the professionals who have followed Jenny in recent years, for finding those ways of doing it, working with the companies and universities, and really gel this to a finely honed team that is very motivated—not just to help us do our job, but also motivated for their own purposes. I hope in the end that a lot of what we've built here is going to lead to a great deal of business in the future, and in doing so provide a great deal of the support and resources that we can then use by taking advantage of the fact that there are markets out there largely responsible for supporting the continued development and operation of these vehicles, and that we can take advantage of that in having lower-cost operations to do our science.

As I said, ERAST has adopted quite a few planes. And I think certainly we've worked very hard with five of them. Three have already flown above 60,000 feet. In fact, the ERAST Program has set three world altitude records, particularly using the solar powered Pathfinder—the predecessor to the Helios that you saw today, which flew to an amazing 82,000 feet. That's the highest flight for any propeller-driven aircraft.

Besides altitude, there are other goals for the ERAST Program. One is long-duration flight. And we heard about the discussions of that this morning—looking anywhere from 12 hours at very high altitudes to as much as 6 months at more moderate altitudes. We also need to work with the aviation authorities to clear the path for regular robotic aircraft operations in civil air space. In particular, an ERAST member, Glen Witt, who's a former FAA official, is working together with the University of New Mexico to establish a flight test range for this very important development.

Finally, we don't know what else can be done. But certainly the idea is to promote not only the needs of NASA's science missions, but also to try to do what we can to foster the commercialization capability within the domestic aircraft industry. And this event today should make it clear that we are serious about helping these companies develop the technology and develop the capabilities that will allow them to create products that are used in many, many ways. At the same time, we can only go so far. Private interests, such as those of you represented here, must help pick up the slack and carry us the next steps. We're not going to abandon the program. But we think that a great deal more ideas and influence (and influence re: money) needs to come in to help guide us into working that way. Events like this are going to help that two-way exchange where we can talk about that.

Lastly, one of the things that—I won't say we've necessarily pioneered—but an important element in doing something new and bold and amazing such as we were trying to accomplish in the ERAST Program gave us the opportunity to add a very important part to what we should also be doing, and that is focusing on developing the pioneers of the future. You'll hear a lot more about that when Marianne talks about it. But I've personally committed myself not only to adding resources to bring the education component that a program like this can bring to bear but also to bring it out to students, whether they're high school or sixth grade or whatever. But this is another very important thing that we can do.

I mentioned that I'd cover partnerships. The roster of ERAST partners has grown over the five years. The four original aircraft manufacturers still make up the core team. But 28 other entities have all come together to work in this activity. Their contributions have been all the way from very fundamental, such as thermomechanical systems, development of double and triple turbocharged engines to supportive activities such as University of Hawaii's help with some of the flight tests that we had with Pathfinder out on Kauai.

Coming together is not bad. I'll tell you that these companies are indeed serious competitors as well. When we began, in fact, most of the companies were quite apprehensive about getting together and sharing the wealth and working closely together. But I think over time and with a lot of work—and I owe that to a group of lawyers that we had working with those delicate negotiations—the company AmTech, that had worked with NASA before in trying to facilitate other businesses, did an amazing job working with each group with NASA and negotiating the best possible of all deals.

Along the way, the alliance has also formed relationships with many others, particularly the Department of Energy, where we had a shared science campaign last summer—again looking at gathering information about global warming and the energy balance that we have here on Earth. ERAST

has also worked cooperatively with the U.S. Forest Service. Another area that you're going to hear much more about is with the U.S. State Department, looking at disaster management.

We're looking forward to forging even newer and greater partnerships with other prospective users of the type of vehicles that ERAST can produce, whether these partnerships are with other agencies, universities, or for-profit organizations. I think we need to continue increasing the partnership to explore the value of these aircraft for any scientific, civil or commercial applications.

For the future, we do have plans to still try to conquer the 100,000-foot goal. We have started in earnest putting together the technology requirements and the needs and the supplies that we would have to make Helios the aircraft that tries to achieve that goal in 2002. Along the way not only do we need solar cells, but we need a more efficient energy storage system, not only to help support the high altitude goal but also to support the long endurance. We're very actively pursuing development of a regenerative fuel cell that will be very small, very lightweight, and allow us the ability to stay on station for months.

At the same time, we'll continue to pursue flight tests and engineering tests so that we can ensure that the reliability continues to be improved and that the safety of these vehicles is well understood, further maturing their capability so that when you pick them up and you use them you know they're going to be there to do your job.

We'll also continue to support the science payload mission development. Again, in the end, NASA still has a great desire to use these platforms to conduct science. I think you'll hear a little bit more this afternoon about some of the plans that we have with the Earth Science Enterprise, preparing to put NASA research announcements out, inviting bids and solicitations for conducting missions using these kind of platforms. I hope there are some of you out there who are looking forward to or are interested in making those proposals. Because this was a day that was set up for you as well, to come out and meet the people that you could work with and include many of these concepts in your proposal.

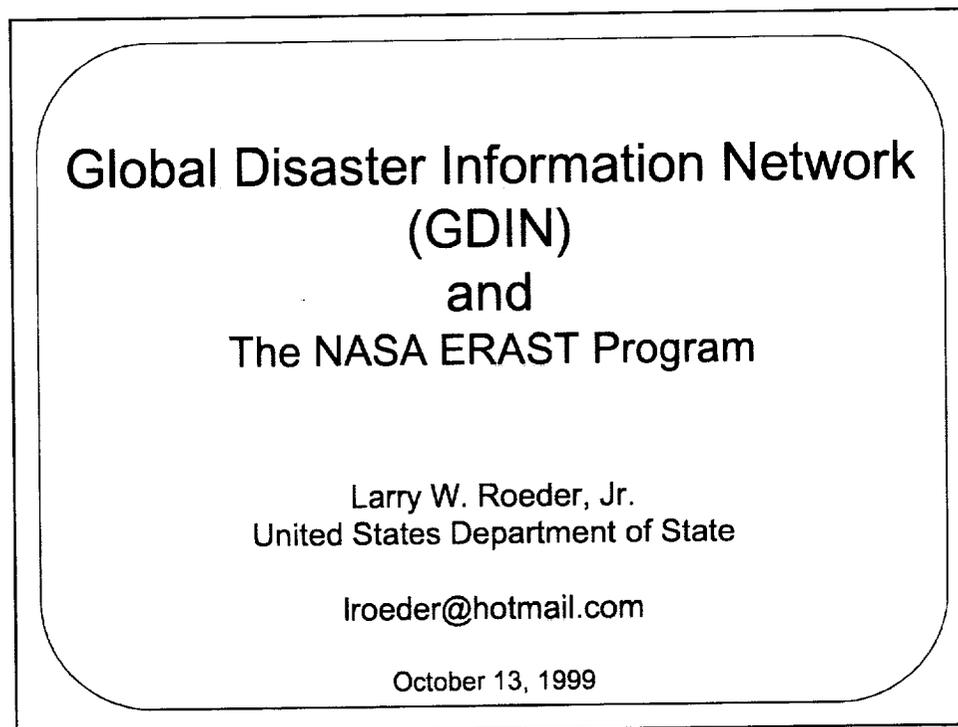
We're still not certain how far we're going to go with this. Again, we're going to try to support the development and nurturing of the technology and the capability for as long as we can, in order that we can get that capability to support the Earth science. We've laid out a plan for another five years. But, again, a lot of that is going to be very dependent on when that precise time is that this market that we think will blossom actually does blossom. I keep going back to a 1992 EIA—Electronic Industries Association—report where the claim at the time—and I know because I used this a great deal in my advocacy of this program—that if we could create this capability by the end of the century, it will be a billion dollar business. Well, if we're going to get there in the next few months, we've got a lot of work to do. But I think the ideas behind their estimates are still out there. I think all we need to do is step up and take the chance. As many of you know, business is about taking chances. I encourage you to do that. And we'll help as far as we can in order to support the needs of the agency. So hopefully there's a mutual advantage to doing that.

Anyway, that's what today is about. I hope for yourselves—I know it is for me already—a successful event. I hope that through the course of the discussions later on this morning and this afternoon that you'll find more stimulating answers and find a great deal more enthusiasm about what we think can be done. On behalf of NASA and the ERAST alliance, I'd like to thank you all for coming. I'd especially like to thank the numerous presenters who are going to be here and have generously agreed to testify to their interests in these aircraft and the needs that they see ahead. I hope you'll enjoy the presentations throughout the remainder of the day.

Next, I'd like to invite Karen up from AmTech—again, another job of facilitating what we do here and there—to introduce Larry Roeder, who's the next speaker from the State Department.

Karen Risa Robbins: Thank you, Rich. I think you can tell he's the godfather of this program. It's my pleasure to introduce to you Larry Roeder, from the U.S. Department of State. Larry is a Senior Policy Advisor, and joined the State Department in that capacity in 1995. That was after he had many years of work in peacekeeping, in crisis management, and in economic sanctions.

Larry has a very extended and interesting bio. I picked out a couple of items that were particularly of interest to me that I wanted to share with you. It's fascinating to know that he was one of the chief negotiators on the Iran hostage team. He is today, the lead for the United States Government in the development of the International Global Disaster Information Network called GDIN. You will hear much about that in his upcoming presentation. It's interesting to note also that in that capacity he recently negotiated the Tampere Convention, which provides for emergency telecommunications in the context of disasters. What it does is to remove barriers to providing telecom assistance across national boundaries during emergency circumstances. Let me bring Larry up then.



Larry Roeder: Thanks, Karen. Good morning. Thanks for offering me the distinct honor to be with you today. This is really hallowed ground for me. I've been following NASA and all of your accomplishments for so many years. To be where the right stuff exists is fabulous.

The NASA ERAST Program is, in the view of the State Department, an American crown jewel, which brings great credit to the Congressional delegations from Hawaii, West Virginia and California and, of course, to our late friend, Congressman Brown. The program also reflects well on NASA and on America's industry as a whole. For without industry and its synergy, there would be no NASA. The Department of State has been on a journey with NASA in search of innovative approaches to disaster management, which is what I want to talk about today. What we have discovered is that ERAST is clearly

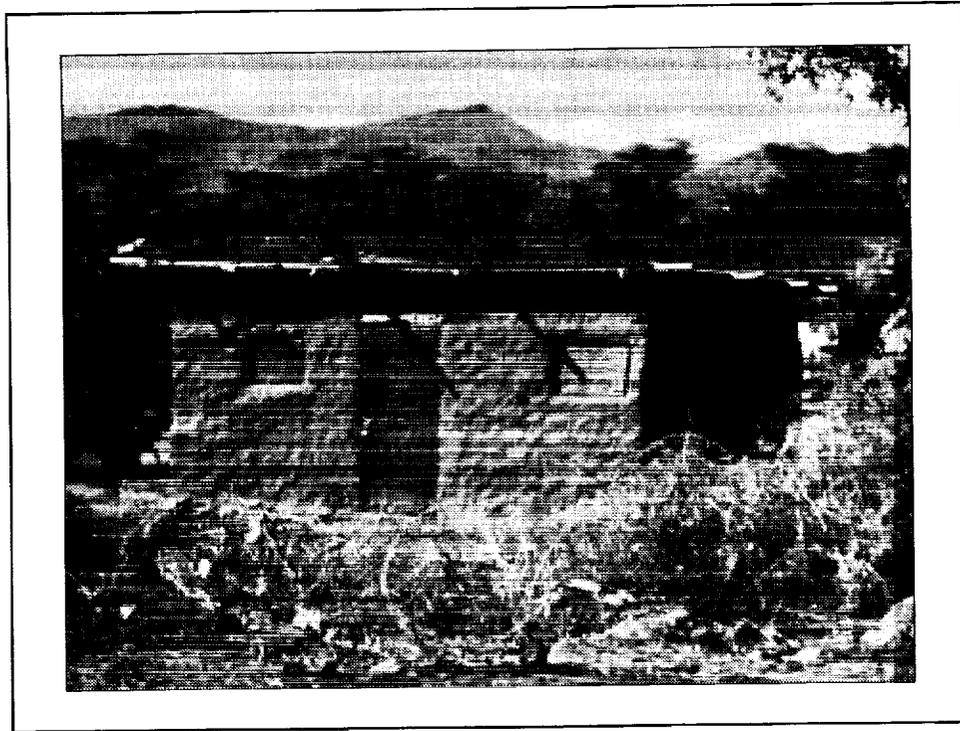
on the right track to do that and also to develop commercially valuable products. In addition, NASA ERAST work is essential to the economy of the whole country. In fact, NASA ERAST offers enormous hope to the world economy and to my special field of crisis management.

When I was born in Lebanon, a neighborhood nearby was destroyed by civil unrest. Between then and when I was eight, the age my son is now, I lived through a civil war in one country, an invasion in another, a forced evacuation under fire across the hostile desert at night. I also survived an earthquake and a locust infestation. I was almost shot in Cuba. Once, while seriously ill, I had to be transported by bailey-seat between ships in the Mediterranean, and I had to make an emergency landing. So my introduction to crisis management came rather early—all of that by the time I was eight years old. I wanted to find solutions. I provide those anecdotes because my son is eight, and the world that he is growing into is more dangerous than the one I was born into.

NASA has always been America's great innovator. ERAST solutions, for all of us today and those of industry in general, can change the dangerous world I just spoke of just as surely as Neil Armstrong changed the world of my youth with his walk on the moon. Today we have just as many conflicts as when I was a kid, perhaps more. In addition, we have a rise in the number of natural disasters and their costs. Take hurricanes—like the one that recently devastated North Carolina. On average, ten hurricanes form in the Atlantic and the Caribbean every year. A third hit U.S. territory. And while our fatalities and injuries are declining, thanks to improved early warning preparedness due to FEMA, NOAA, NASA, the U.S. Geological Survey and others, economic losses are skyrocketing. A major hurricane has the potential for more than \$30 billion in losses to the U.S. economy—one hurricane. The point is that these storms could render insolvent a third of the U.S. insurance industry.

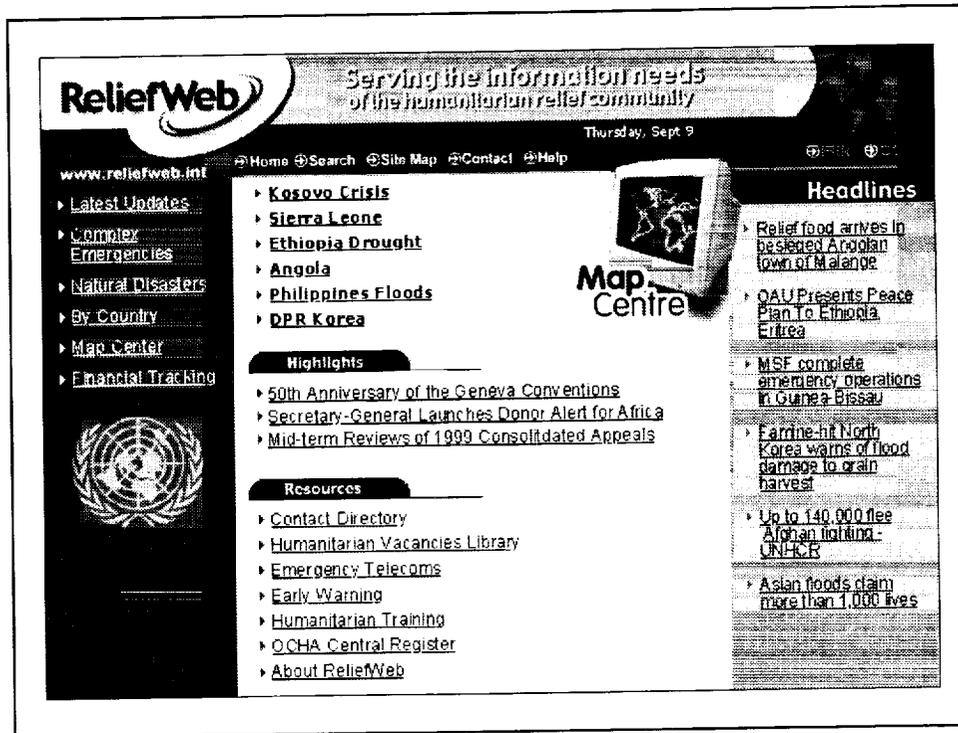
A driving factor behind increasing losses is population growth in disaster-prone regions. In the United States alone, the coastlines have seen an annual growth rate of three to four percent. People are moving in the direction of danger. That population translates into enormous capital risks. With people come homes, bridges, buildings, all manner of infrastructure, all manner of risk. As a result, in the United States we are losing a billion dollars a week to natural disasters.

Now think of the rest of the world where there is less infrastructure. The annual losses to the world add up to nearly half a trillion dollars a year. Kobe alone cost over 150 billion dollars. If we had a repeat of the 1906 San Francisco earthquake or the 1857 Los Angeles earthquake, \$200 million right there. If Tokyo was hit again as it was in 1923, there would be a cost of one trillion dollars in that one incident. And think of the lives. What would happen if a liquid petroleum gas tanker exploded in Istanbul. That could happen. The recent event in China killed 240,000 people—the earthquake. Some reports suggest 750,000. Even more frightening is that many of these events happen where there is no infrastructure. This is a picture of a mud hut that I took a few weeks ago on the border of Sudan. These people have no insurance, no early warning, no infrastructure at all. They need us desperately. The bottom line is that natural disasters are systemic risks to world societies. Events triggering a chain of events that cripples the society and where repairs can't be made in the short term without incurring very considerable costs. These disasters hurt every sector—health, transport, energy, water, telecommunications and, of course, the environment.

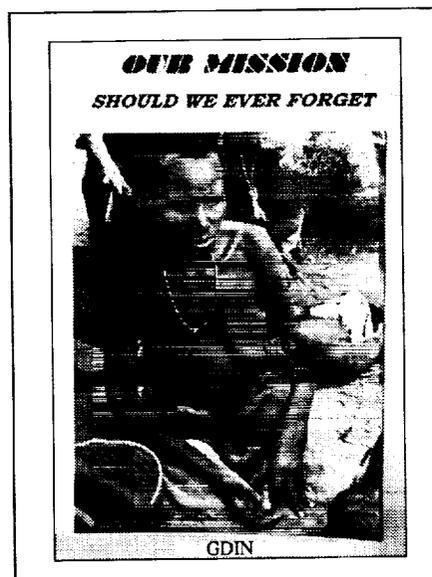


What I do is crisis management. And I will tell you that managing this new class of risks constitutes a critical, dual challenge for governments and the business community—one that will only grow in the next millennium. So my speech is really a call for unity—the dividing line between the responsibilities of the market and those of government must be re-examined. We must share the tasks and responsibilities among individuals, academia, business, governments, the volunteer agencies and, of course, the international community—just as ERAST has done. We must do this because of a growing interdependence and complexity of society and because of the nature of these new systemic risks. In other words, we must be partners—not competitors. And, again, ERAST is the model for all of us.

Now my current job in the State Department derives from the Rwanda crisis in 1995. We realized that international disaster managers were not talking together as well as they might. Disaster information was not flowing smoothly. So we developed specially designed products such as relief web. This was the first international website that focused on disasters where the United Nations has been asked to play a role. It's been endorsed by the entire United Nations General Assembly. At the time, in 1995, the Internet was a fairly new product for those of us who do disaster management.



Another product under development now is GDIN—the Global Disaster Information Network, an international partnership begun by the United States and on the international side led by the State Department and AID to convince all sectors to share disaster information from all sources at the lowest possible cost. A big part centers on the use and distribution of remote sensing information. From ocean sensors like we use to predict El Niño, ground centers like we use for earthquakes and volcanoes and, of course, overhead from satellites and airplanes. Now why will we do this. This is one reason. This picture of malnutrition was given to me a few weeks ago, again, on the border of Sudan, by an Irish relief organization named GOAL.



Now let me explain how GDIN, this partnership, will help us help that problem and other disaster related problems. Two stories—one a response story, one a mitigation story from 1996. In December of that year I received an e-mail message from Nairobi saying that a volcano had just erupted in Virunga National Park in the former Zaire. Right below the volcano was a series of refugee camps. There was a real fear that lava would come down and wipe out thousands of people. There were also refugees along one slope. Well, they said, give me satellite imagery. I was looking, at the time, at a photograph about this big taken by commercial satellite some weeks earlier. I thought, if I try to e-mail that to East Africa, it will take about three years to get there. So instead I found a satellite that day that happened to have the right sensors, and I had the information converted into what we might call a derived product—a map about this large in black and white showing the contours of the volcano, lava flow, vents, that sort of thing. And we used it within eight hours to save people's lives. That's the right information, right format, and the right amount of time to save people. But what if I wasn't there that day? And even if I was there, what if there wasn't a satellite? You can't move a satellite to a disaster—not very easily. It's very expensive. But we could move an ERAST platform to that volcano—something Mexico wants to do. You know about Popocatepetl south of Mexico City—a semi-active volcano—and other volcanoes that straddle Mexico. They would like to have your platforms, and particularly Helios, going along the various volcanoes, looking down the calderas at the dome to give us better prediction of when they might erupt.

Mitigation in 1996—a story from California, from Mendocino, California. There was a major forest fire. Burned off trees, shrubs. We had to replant. Harsh winter rains were coming. What were we going to do. Well, what we did was, for the first time we fused together information from a wide variety of satellite platforms, both military and civil—hadn't done that before—as well as information from airplanes, park rangers, feeding information, historical data. We created a model which told us not only what to grow and where to grow it but how much to grow. As a result of that, we saved \$250 million in reduced vegetation at replanting. Just think. If we could take that example and a more effective response example using your technology to the developing world—Albania, Honduras, El Salvador where there's so much deforestation.

Disaster mitigation is not cheap. It requires information and money. No one says your systems are going to replace satellites. That's not the plan anyway. But we believe that your systems will significantly augment the current system—in our view revolutionize disaster information management. I see a world where ERAST does what we did in Mendocino County. Leasing the world your tools to develop mitigation plans less expensively than now, and implement them less expensively. That means smaller and less expensive loans from the World Bank. Debt servicing goes down. That means we have more stable political and economic structures. That's good for everyone. And it defines a world market for ERAST products.

Now here's another mitigation idea. What if we could use the high-grade quality of ERAST data—submeter resolution—to convince ordinary people why they shouldn't live in harm's way. This is something Turkey wants to do. Traditionally, many governments tell people where to move. If you're in a flood plain, move out of there. We're not going to help you. The government of Turkey, the disaster management people have a new idea. Why don't we—instead of developing remote sensing products for disaster managers, like I did with the volcano in Zaire—why don't we develop products for ordinary people that we could take to mayors in small villages who have very little education and convince them, not tell them, where they ought to live so they can survive and so they can prosper. That's part of the vision of the Global Disaster Information Network I mentioned a moment ago. We really believe that your products could be an essential part of that.

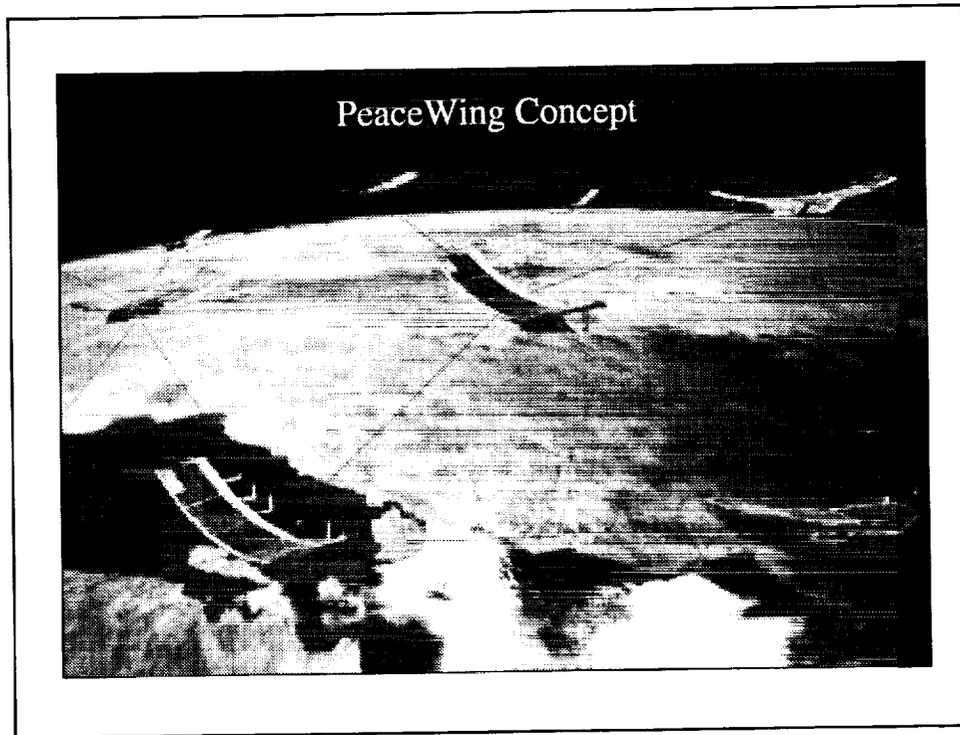
Well, here's another example of partnering I'd like to talk about. [The next two slides discussed are not available to include in the document.] This slide and the next slide are products that a team of people I led put together right after the earthquake in Turkey. Within hours of the earthquake, we contacted the disaster management people in Ankara and in Istanbul to ask them what information they needed in order to deal with the disaster. They had a lot of information, of course. But they said, we need certain specific things sent to us every single day. What we did was we reached out and found what we needed in the way of platforms—remote sensing platforms—and reconfigured the information to show where the disaster was worst. These were GIS products which I then e-mailed towards the end of the day. So for about a week, in the morning we would get a specific request from the Turks saying, tell us something about a specific area in this format, and by the evening the State Department would have a product like that for them, all done by e-mail. It shows the power of the Internet. That is something we want to do through the Global Disaster Information Network on a regular basis. We believe that your platforms could augment the current system of satellites we were using to do an even better job than we did of this. The work is really so very important.

A few years ago while I was a peacekeeper in the Sinai, I flew in a helicopter through a mountain pass one spring and saw settlement after settlement wiped out by flash floods. They were poorly placed. In Turkey last year I traveled through flooded areas between Ankara and the Black Sea and saw apartment buildings where roofs became basements. They were also poorly placed. And you've all seen the pictures of Turkey's earthquake—bad construction. My point again is that international disaster management is too big for government. To succeed as a world we have to work together. Such a partnership is the Global Disaster Information Network. It's an international link between industry, government and academia.

If we work together, the world will get better forecasting and better mitigation and response. Within hours we could reduce the disasters that we had in Turkey, reduce the disasters that we had in China and in Taiwan—save more lives. This would help us develop disaster resistant communities, making North Carolina, California, Hawaii and the rest of us stronger and safer. Some specific examples—evacuations, business closures, can be ordered only when needed. Citizens can be better protected. Unnecessary alarms can be avoided. Insurance rates can be set lower, and markets will be less vulnerable. We can better prepare for international relief efforts, and we can minimize global economic disruptions. The impact on U.S. foreign trade can be reduced. Airlines and shipping will be safer, and oil and gas production will be protected.

But there's a problem. Many countries are afraid of remote sensing platforms. They feel that these platforms will put their economic and national security interests at risk. What we need is a way to both use the technological promise of the Global Disaster Information Network to mitigate and respond to disasters as well as protect those economic and security interests. Here, ERAST can play a key role.

What I want to talk about now is Peace Wing. At the Mexico City GDIN Conference in May, we introduced ERAST to many disaster experts of Latin America and the rest of the world. They were very impressed. So, too, were all the experts I spoke with a few weeks ago in Paris at a meeting of the OECD—Organization of Economic Cooperation and Development—as were African experts I met, with someone from NASA, in Kenya and on the border of Sudan last month. What we proposed was Peace Wing—a GDIN-related concept using ERAST technology to provide the very best in submeter remote sensing and telecommunications without the risks. Our plan is to fly Helios over a portion of Africa next year to test the Peace Wing concept.



The planes we want to use were developed by your AeroVironment partner because they are solar powered and because they are transparent. You can see right through them. The venue for Peace Wing, again, will likely be Africa. Large numbers of animals migrate traditionally between Sudan and South Africa. This is also where a drought is building. Drought mitigation therefore is essential. With drought comes malnutrition, pneumonia, dysentery, other diseases, and political unrest. Assuming all goes well, our plan is to pick a group of experts from industry, the United Nations, local governments, perhaps the Kenyan government, etcetera, who are interested in environmental and disaster issues.

Each partner will pick off-the-shelf sensors themselves, put them on the plane. Remember, the plane is transparent. The idea is that they know exactly what's on the airplane—no hidden doors. This is not on a military plane. This is not a spy plane. This is a civilian plane doing a civilian function. When we showed pictures of Helios to everyone—the military, the civil side, the United Nations, whoever it was—they said, this is intuitive. We understand this right away, how this could be used. We're not afraid of this. Each partner would jointly select what sensors it put on. And then the plane will fly over a jointly selected flight path for a few weeks to examine the land, its rare animals, do population and environmental impact studies, test the techniques used in disaster management and cell phone telephony.

Again, over a disaster you can't move a satellite. You also often don't have telecommunications. Wouldn't it be wonderful if we could not only move a platform over a great flood to find people in trees—a real problem in Somalia. But what if we could also—in North Carolina, down in southern Mexico, wherever it is—have instant telephony so relief workers could communicate, looking at the data, finding people, talking to each other to guide folks to where help is needed.

The plane will also be on radar so we know where it is at all times. All the data will flow down into a control room live where all the partners are. Again, the idea is transparency. Everyone knows what everyone else is doing. Again, it's not a military thing. It's not a spy thing. It's a civilian plane doing a critical job really well.

## Sensor Technologies

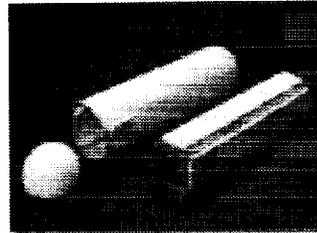
Airborne Real Time Imaging System  
(ARTIS)



High altitude Optics



Digital Array Scanning Interferometer  
(DASI)



Slide 1

May 3, 1999

 AeroVironment, Inc.

In North Carolina dead pigs are floating around. People are sitting on roofs. Pollution is flowing into wells. Animals are trapped. ERAST technology could detect all of those disaster situations using resolution levels at submeter level, geocoding problems, directing relief workers to where help is most needed. There's an enormous market for your products.

In our Peace Wing experiment we're also going to surround the control room that I talked about with trailers linked via Intranet. Inside any one of these trailers you might find an expert in one particular area—black rhinos, for example. It tracks individual black rhinos by flying with the sensor. There might be somebody who does population studies looking at the data, flying with the sensor to do that. What I want to do here in this controlled way—this political experiment, if you will, demonstrating this thing can be done safely—is illustrate a future world where ERAST is flying over a disaster such as, again, a flood in North Carolina. The experts don't have to come to the disaster to help the folks on the ground fight the disaster. Maybe the world's experts on pollution in the water happen to be halfway around the world. Again, disasters happen when you least expect them. Why should we fly the world's expert on pollution to the disaster? Maybe there's another disaster on the other side of the world. That's awfully expensive, and people can't bi-locate. So instead, it would really be wonderful if one expert could have on his TV screen possibly five or six disasters going on at the same time, or looking at five or six views of one disaster at the same time, even though he's a thousand miles away. That's enormously powerful, and it isn't done today. You guys can make it happen and save a lot of lives, save a lot of money.

Park rangers in Kenya want to use Peace Wing cell phone telephony to find smugglers, poachers, and then tell their other park rangers where to go and what to do when they get there. Enormous value.

## Virtual Operations

The diagram, titled "ERAST TELESCIENCE", illustrates a remote sensing system. On the left, a satellite is shown in orbit, emitting a signal towards a ground station on the right. The ground station is depicted as a large structure with a dish antenna. Below the ground station, a map of the state of Florida is shown with a sensor array (represented by a grid of small squares) positioned over the state. An arrow points from the sensor array to the ground station, indicating data transmission. The entire diagram is enclosed in a rectangular frame.

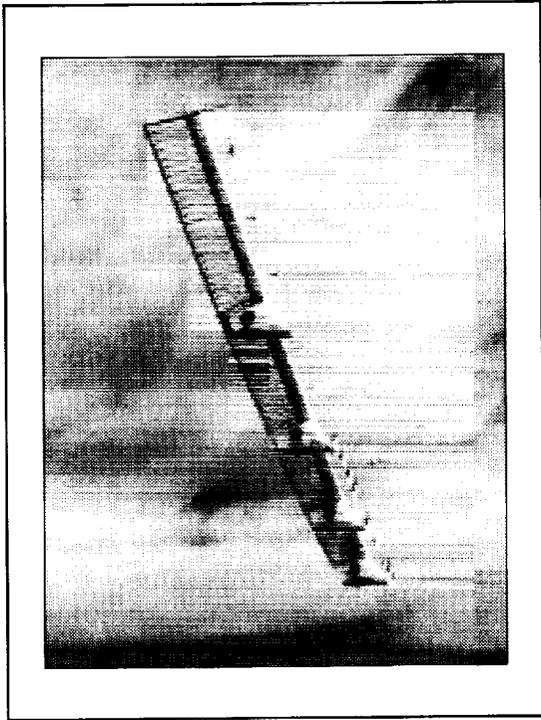
**Near-real-time remote sensing operations using the Internet**

Slide 2      May 3, 1999

AeroVironment, Inc.

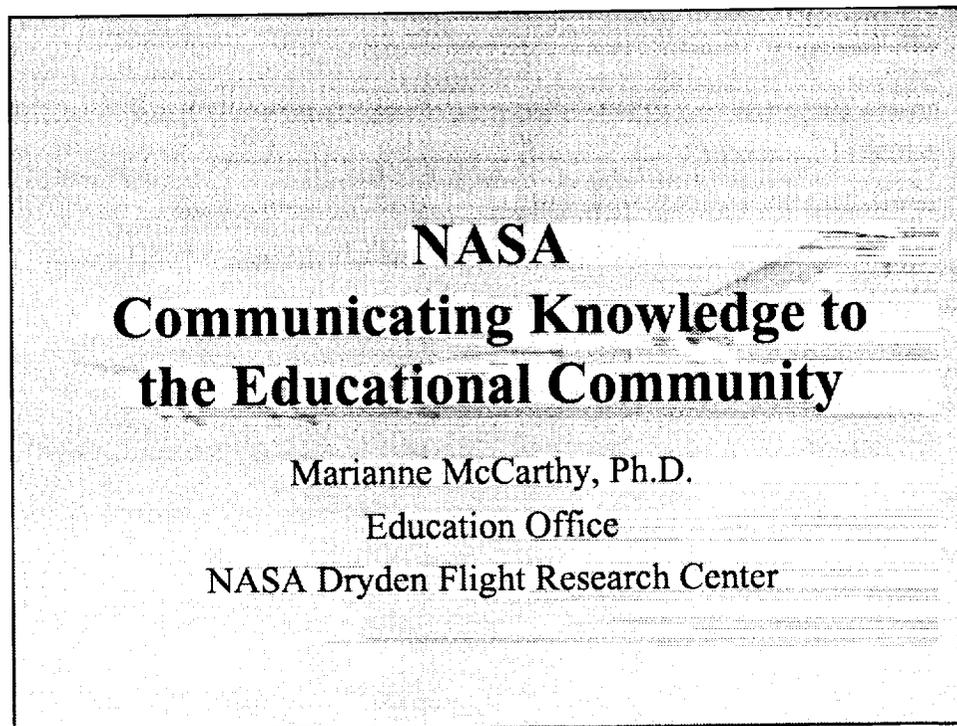
What we want to do is test Peace Wing. We call your plane in this context Peace Wing. We call it a sophisticated simulation of a disaster done under controlled conditions that also shows local leaders it can be done without risk. If successful—and we believe we will be successful, given the reaction we’ve had in Africa and Europe and in Latin America—we hope to stimulate broad use of your technology in the developing world for both commercial and disaster applications. I would add that this concept will be discussed in detail at the April 26–28 conference in Ankara, Turkey on the Global Disaster Information Network. At that conference we’re going to be talking of course, about the earthquake that has happened in Turkey and how a GDIN, if it had existed a few years earlier, might have caused fewer buildings to collapse through better building codes based on better data from remote sensing, and we’re going to talk about how a future partnership involving all sectors, including your sector, could do that in the future.

So in conclusion, I would like to mention that over 2,000 people were killed in the earthquake in Taiwan. In addition, two weeks ago a thunder clap that sounded like dynamite reverberated in southern Mexico, and the town of La Aurora slid off a mountain. Over 200 may be dead under mud—90 percent women and children, according to the press reports. Over 400 are known to be dead in nine of Mexico’s 31 states—over 200,000 homeless. It’s going to take years for those states to recover. It’s to those people—the folks in North Carolina and other victims of disasters around the world—that this speech is dedicated. With your help industry, government, the United Nations, relief agencies around the world working together can use ERAST technology to revolutionize disaster management and save a lot of lives. Thank you very much.



Karen Risa Robbins: Thank you very much, Larry. This is really an example, I think, of swords to plowshares—knowing the original genesis of the technology that Rich Christiansen spoke of earlier. Finally, this morning I'd like to introduce Dr. Marianne McCarthy. As Rich mentioned to you, education has been a very important theme of ERAST in addition, of course, to the important work in R&D and also in reaching out to the user community. But there has been a great recognition—and this is true throughout NASA—that education is an important part of the mission. I won't detail for you some of the amazing things that have happened in education. Marianne perhaps will do that. Let me just tell you a few things about her.

Her own background is, of course, very distinguished in education and she was a principal of a high school at one point in time. In that venue she worked with NASA on a computer technology project. That led to her familiarity with NASA and NASA Dryden is with her. It was at that time NASA decided to create an Education Department, and they were very fortunate that Marianne was willing to come and lead that department here at NASA Dryden. So let me introduce Marianne McCarthy.



Marianne McCarthy: I'd like to start by talking about the vision statement in NASA's strategic plan. NASA is an investment in America's future. If we are to actualize this vision statement, we, as an agency, have to communicate knowledge. We have to communicate the knowledge of what research and development are doing for you, and also for the educational community—for the young.

## **Vision Statement**

**NASA is an investment in America's future. As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on Earth.**

NASA has a commitment to educational excellence. We want to involve kids, even as young as the kindergartners and the elementary students, in our missions. The reason I was asked to give a presentation at this event is because ERAST was my partner in conducting a successful education outreach program. The program was so well received that it is considered a model partnership between a center education office and a research project. The ERAST partners were willing to work with me from the very beginning. The technical people helped me formulate a method of translating the very sophisticated aeronautical technologies generated by the ERAST program and get the concepts across in a meaningful and useful way to a third grade teacher in Iowa and her class of eight-year-olds.

How were we able to do this? I found in Jenny Baer-Riedhardt an excellent and open partner. As a result, we were able to do extensive educational outreach and formed a comprehensive education program around a flight research project. The education outreach was very rewarding. It is always gratifying for us to work with teachers and students. Our office developed an educator guide that provided background information and was the translating tool to make the connection between the core curricula teachers are required to teach and the applied science going on in the ERAST program. The educational guide used Pathfinder's research as a context for teaching science, mathematics and technology. We conducted 20 different workshops and over 200 teachers were involved in this initial outreach effort. Following the teacher workshops, we worked with the state science supervisor in Hawaii, the local school district on Kauai, and the Pathfinder project team to organize an open house at the Pacific Missile Range Facility. On that day, we set up learning stations for the kids and over one thousand students and teachers participated in the event. The outreach effort culminated with a dedication of the ERAST record-breaking flights and technology development to Ellison Onizuka, our only Hawaiian astronaut, who perished in the Challenger accident, and to the children of Hawaii. We received recognition by the local community, state and congressional representatives as a result of this effort.

## **Educational Excellence**

**We involve the education community in our endeavors to inspire America's students, create learning opportunities, and enlighten inquisitive minds.**

## **A Model Collaboration**

- We wanted to develop a new approach to working with NASA engineers and scientists to conduct education outreach**
- We developed a method of translating the knowledge generated by the research into material that could be used to teach science, mathematics and technology in an exciting way**

## **ERAST Education Outreach**

- **Teacher Enhancement Programs**

**Conducted teacher workshops on the islands of Kauai, Maui and Oahu; Served over 200 teachers from 20 different schools**

- **Created an Educational Guide (learning activities) by working with Pathfinder scientists and a team of K-12 teachers**
- **The Educational Guide uses Pathfinder's research as a context for teaching science, mathematics, technology**

## **ERAST Education Outreach**

- **Student Programs**

- **Worked with State Science Supervisor, the local school district, the Pathfinder Project Team and the Dryden Education Office to organize an Open House at the Pacific Missile Range Facility**
- **One thousand students and teachers attended the Open House**
- **Culminated Education Outreach with dedication to Ellison Onizuka and the children of Hawaii**
  - **Recognition by Congressional representatives**

## Future Possibilities

- **As you have seen and heard, the ERAST aircraft have applications ranging from disaster assessment to crop management to storm tracking.**
- **Imagine students and teachers working with data, video, and images in real time to study science, math, geography and technology**

In terms of the future, the ERAST aircraft have applications ranging from disaster assessment to crop management to storm tracking. What I am looking forward to is the opportunity to develop educational programming that enables teachers and students to learn using real-time data and images downloaded to a student's desktop. I had an interesting conversation with the gentleman from Boeing last night. Technologies are changing so fast, we can forget about the desktop. We're going to download images, information and data to a belt, and the students and teachers will have mouthpiece and a heads-up display. The point is that by using actual research as a context for learning, you can do all sorts of simulated or real scenarios for kids. Opportunities to function like real forest rangers, scientists or pilots captures their imagination and inspires them to continue to study science, math and technology, and to keep America preeminent in aeronautical research.

### A question about distributing information.

Marianne McCarthy: The package we developed is going to be distributed through NASA's Educator Resource Center Network. The products are being reviewed at a Headquarters level now. There is a suite of products including an educator guide, poster and a video fact sheet. The video fact sheet gives the teacher background information to share with students and also provides a visual demonstration of what the aircraft is capable of doing. They will be made available free to educators. The product will also be made available through NASA's Central Operation for Resources for Educators.

Question: How could we get this information to a teacher?

Marianne McCarthy: Well, you could contact me. There's also several NASA education websites with information for teachers. I would be happy to answer your questions. If I don't have the answer, I will redirect the question or request to the proper person.

Karen Risa Robbins: What is your website address?

Marianne McCarthy: You can start at [spacelink.msfc.nasa.gov](http://spacelink.msfc.nasa.gov) or [education.nasa.gov](http://education.nasa.gov).

Question: With respect to the restrictions on flying these autonomous aircraft, how are we going to approach that or what are the possibilities of flying these over the CONUS, and also at what altitude do we need to fly these things in order to obviate the need for special permission to fly over other countries?

Rich Christiansen: Well, I don't have a lot of details about other countries in mind. But let me talk about the first part. Unrestricted operations in the normal air space are a little ways off. What we have to work right now is taking off and returning back through that air space. How we do that today, of course, is through use of controlled airspace to go out and come back. Our hope, though, is that we could get to a point where we go in and out of commercial airports. And that's why we need to do some demonstrations. Because the uncertainty of having a vehicle without a pilot in it is perhaps nerve-wracking to pilots who are flying in the same airspace. And it's mostly just a transient issue right now. Most of the work that we're looking at will be far above the normal traffic lanes, greater than 40,000 feet. Once we get there, there shouldn't be any real issues flying over the U.S. I don't have all the details on that. As far as operating out of other countries, there's the normal work that we go through with the State Department and things of that nature. In fact, there are some countries that just won't allow unpiloted vehicles to fly over their airspace. We've come across that. That's more of a governmental policy issue that we have not taken on yet, because we're not ready to do it.

Question: One of the issues, of course, in any project is insurance coverage. At a higher level have you had discussions with entities that might address insurance coverage at some point for the ERAST platforms—if they're over metropolitan or rural areas? Or is it premature to be having those conversations?

Rich Christiansen: We covered the issue of insurance early on in some of the discussions. I'll admit not being up to date. My belief, though, is that each company right now that's working with us has its own insurance policy. Again, within the limits of flying within the restricted zone, recognizing it's a prototype, a test vehicle and they're not going into operations. But I think, again, it's a question of reliability. In the future as we begin to demonstrate greater and greater reliability of these operators, the insurance will be more available and less costly.

Question: The gentleman from the State Department talked about doing things from remote control for disasters, and so on. Is your program working on uplinks to satellites for these vehicle packages or sensor packages, or is this all on another program someplace?

Rich Christiansen: No. We have looked at it from the prospect of operations over the horizon. And I believe some of the experiments we've looked at in doing the uplinks have been through the TDRSS [Tracking and Data Relay Satellite System] satellites that NASA has up there. Again, it's experimental. I won't say for a fact that we've worked out all the bugs. But, yes, that's a part of ERAST.

Question: Rich, you talked about the controlled air space aspects. I was wondering if you expect the FAA [Federal Aviation Administration] or the NTSB [National Transportation Safety Board] to work cooperatively with the ERAST Program whenever you have an incident where an airplane goes out of the controlled air space. Will that be a problem for your program?

Rich Christiansen: From day one, FAA certainly has been cooperative—I mean to a T. Not only is it working with us, but it is also working with the Department of Defense to try to understand what the issues are. They began writing a circular about three or four years ago to begin looking at what some of the issues are. So they're working with us. It goes both ways. We asked them to work with us early. That is something that allowed them to get in at the beginning of the technology area so that they aren't playing catch-up. They're with us every step of the way. So it's been collaborative all the way. As far as

NTSB is concerned—I think that has to do with some next steps in trying to consider the commercial ventures that go out and how that goes. Currently, most of the operations—in fact I think all the operations—are covered by the NASA policy and guidelines. And if we have an incident, we cover that. So it's a government-sponsored activity at this time.

Jenny Baer-Riedhardt: I want to thank Rich for giving me part of the spotlight. I'm Jenny Baer-Riedhardt. I was the Program Manager with the ERAST Program during the early stages. What we're going to be doing right now is we'll invite you to go down to the hangar and actually see the airplanes up close and personal. Not too close—please don't touch. Also, we have the luncheon set up down there. We will then resume back up here in the Mezzanine for the Plenary Session this afternoon. So thank you very much.

## **MEZZANINE PLENARY SESSION**

## MEZZANINE PLENARY SESSION



Jenny Baer-Riedhart: My name is Jenny Baer-Riedhardt. I was the ERAST Program Manager. I'm now the Deputy Chief of the Public Affairs, Commercialization, and Education Office out here at NASA Dryden. I've moved on to work more outreach efforts, not only for ERAST but also other programs.

What I'd like to do this afternoon is give you a pictorial summary of what we did with ERAST. Rich did a very good job on giving you the details and the history of the program. I'm going to give you a slightly different perspective about how ERAST came about and also a little bit on what accomplishments we've had over the past five years. This will go up to about August of '98, at which time I transferred out of the program and we started the transition with Dr. Jim Stewart and also John Sharkey, who were the follow-on Program Managers. John will go from that transition to present. So it's sort of a two-part series.

One of the things I might mention is that, as Rich said, we started out with primarily the four main companies and also with AmTech, which is a non-profit organization that works at doing facilitator work in developing joint sponsored research agreements and partnerships. I would like to recognize Karen Robbins and Eric Brockhauser, because they were the ones that actually helped me work with the 17 lawyers. We went from an 8-page document up to 91 pages.

Before the ERAST program, there was actually the Truckee Workshop, where most of the scientists got together and looked at what kind of platforms they wanted for capabilities to do some of the atmospheric type of work—primarily in the *in situ* measurements area. What came out of that workshop was looking at platforms that could fly higher and longer than the current piloted airplanes, primarily the ER-2 and the DC-8—also ones that could go in and do more hazardous missions than they've been able to do with those two piloted airplanes. As part of that workshop, the SHASA Program came into being,



which was Small, High-Altitude Science Aircraft. That was done with the Perseus A aircraft with Aurora Flight Sciences Company. That airplane did some initial work. There were two main things that we found on that airplane—one, that we did have a closed cycle engine, which was a brand new technology that we were able to operate up to 50,000 feet, which was a very good plus. The other thing we found out was that the technology to do these kinds of high-altitude, slow-flight missions was really not quite there. It wasn't mature enough to do the faster, better, cheaper type of approach that we wanted to do within NASA as we started to change the image of the agency to get things done a lot quicker. So it became ERAST. ERAST was looking at doing rapid technology development. We wanted to look at reinventing the government. We didn't go out with the standard contract. The approach was: Well, you know, we've got a big challenge with technology. Why don't we make it a little bigger, and let's do an experiment on how to do management and government partnerships. We actually had a government-industry partnership. There are some key things in this, in that the people in industry were the ones who led in the requirements of the technology and what we needed to work on. They also had to look at what the NASA mission was and be able to develop technology that would suit both our mission and the requirements for commercialization.

The other part of it was that these industry partners did not get any profit or fee from this. In fact, they had to provide in-kind resources, which was in facilities, technology, funding, or whatever they chose to do. We had a very good working relationship. It was a little tricky at times because since they weren't getting paid with a profit or fee, it was kind of hard to get people to work. It was sort of an exercise in motivation. But it did work. We went from 4 companies up to 28 companies as part of the alliance activity.

# The Emergence of ERAST

Re-Inventing Government



Industry Development

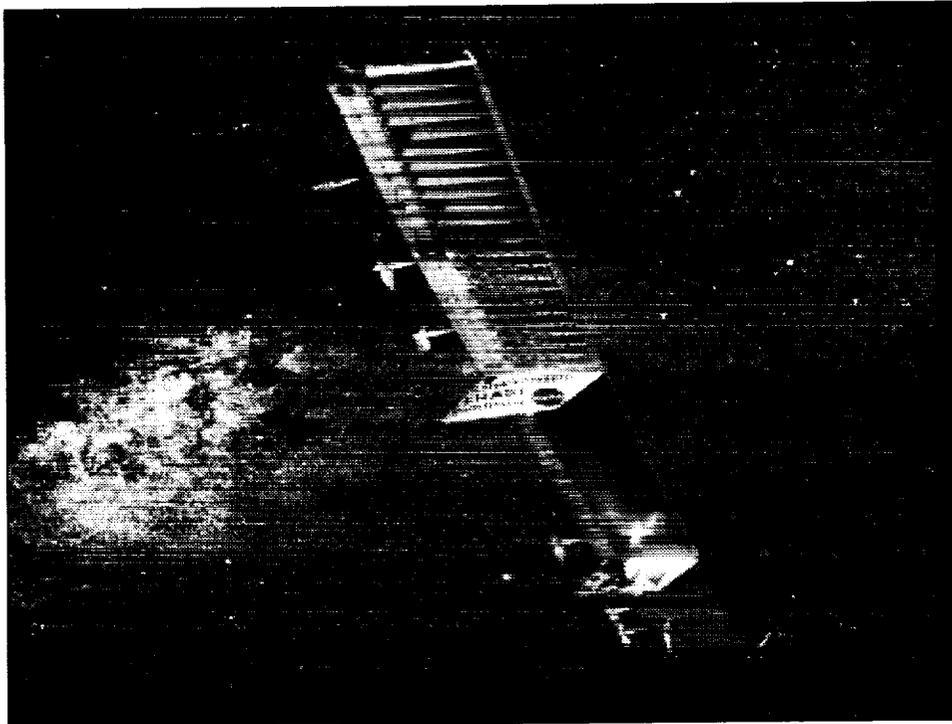
Government-Industry Partnership



Dryden Flight Research Center



Dryden Flight Research Center



What did we accomplish? We had the Perseus A Program. Before it came in, we had the D-2 with Scaled Composites. The work that was done under the D-2 Program involved the flight control system, auto pilots, and some of that work on remote piloting, TDRSS, which is the satellite day-link-testing with payloads—all that work was done. Pathfinder, Pathfinder Plus, which went up to 80,000 feet. We've got the Perseus B aircraft. We've got the Altus aircraft that completed a science mission over in Kauai. We looked at the very, very high altitude with the Apex Program looking at unique structures, advanced boron composite structures for ultra light wings. We also had the pointer aircraft, which did volcano sampling over in Hawaii to look at flying these things in hazardous missions. We had the Alliance 1 all four companies actually contributed to the design of that program, looking at three-stage turbocharged systems so that you could fly above 80,000 feet, looking at low Reynolds number inlets, heat exchanger designs that are required, etc. Of course, we also then came into the Centurion, the Helios. We did sensor work. We have an instrument that was developed by Harvard under the program. Again, looking at small, lightweight sensors, we have the ARTIS, the Daisy, and also the Argus instrument that were all developed.

We also worked with the Office of Naval Research and the Naval Post Graduate School. Under that program we did joint funding, and we actually did a lot of other sensor development work. Many of those sensors are actually being used and co-funded by both agencies in doing some of the science work that we have today. We'll be going on in the future.

I'd like to introduce Dennis Reinhardt right now. He's the Director of Remote Sensing for the Risk Management Systems, Inc. He has had an illustrious career and experience in doing remote sensing work in applications in the environmental area in particular.

Dennis Reinhardt: [Slides unavailable] What I'd like to do for a very few minutes is talk about remote sensing as it relates to the insurance risk business. I should say risk insurance business, because we look at it broadly as encompassing all kinds of risks, even noncatastrophic types of risks.

In reflection on Larry's talk, I wholeheartedly agree with almost everything he said. In fact, I don't think there is a single thing I could pick out that I didn't completely agree with and find in parallel with our activities in the private sector to be on line with what Larry is proposing to do. We have a big problem in the private sector, however. That slide was intended as a portrayal of the kinds of things that we do at risk management solutions and/or MSI in India, our primary subsidiary. We're built around a worldwide model of risk modeling and advice to insurance companies. Three-quarters of the world's largest insurers are our clients. That's not so important. It is financially. But what's important is the long run—in the way that we evolve our business. What I had hoped to lay out here for you is what we find wrong in terms of the data that we gather, what we're doing to solve the problems of data acquisition, and so forth. But that will come out in the rest of the remarks.

Now, anything that happens that is of a major problem in the world like the earthquake in Turkey, where buildings crumbled atop each other, where bridges fell like matchsticks because the design had not been followed or something was wrong in the follow-up regulatory process, where a major oil refinery erupted. What the previous slide was showing is moving from earthquakes in Turkey. When I showed the oil refinery I wanted to illustrate a major fear that we have in Tokyo. Tokyo is a possible tinder box, with its oil refineries and other facilities that are explosive in close proximity to major human populations. A major earthquake in Tokyo would be a true catastrophe.

We've moved into places like Nicaragua. Of course, every time there is a major event out around the world, we send a field crew out. And we hopefully then support that field crew with remote sensing information. In the case of Turkey, we started to seek remote-sensing information—got some low level shots, which I showed just previous to this—then tried to get high resolution space imaging but couldn't get it. SPOT (Satellite Pour l'Observation de la Terre—satellite for the observation of the Earth) offered ten-meter resolution, which wasn't good enough for damage assessment. We got a commitment from the Russians to task a military satellite two months later at submeter resolution, then charge us an arm and a leg for it. We said, "Nothing doing. We'll wait till the IKONOS goes up." Now we have the IKONOS. We even tried to task the Air Force with a U-2 which we thought might be in the region, and we're still waiting for a reply on that. [IKONOS, whose name is derived from the ancient Greek word for image, is a commercial imaging satellite with one-meter resolution. It was placed in orbit shortly before this conference.]

So major frustration in gathering remote sensing information. That's where we look ahead to ERAST. The picture I just showed segues into what we do in terms of data collection. The earth is a seismic region, globally based on the plate tectonics. We gather scientific information and convert and translate that into useable information into our models. We then engage in predictive modeling, which enables us to predict the track of hurricanes on a micro scale—but not accurately enough.

We also have assembled information on multiple perils around the United States. We can do this around the world. We have sufficient data which might guide the location and the strategic positioning of ERAST vehicles around the world. We'd like to suggest that as an approach. Come talk to us. We look at hurricanes in detail, trying to pattern them and to identify where they're going to hit. But, as you've been observing lately, most of the time it's off. We like the ERAST aircraft for reasons that were spelled out

earlier today for scientific data gathering. We base almost everything we do on good science, but also on some intuition.

Now what is remote sensing? To us it's everything. It's using all sources of legitimate data. And we believe that ERAST in that context is a major mid-range addition. We need high-resolution data. ERAST aircraft can obtain submeter data with various sensors. We need spectral data. We need hyper spectral data—new instruments that are now being flown to gather electromagnetic spectrum definitions across the board in microchunks instead of six or seven or eight bands.

Now, here's your competition in satellites. About a dozen are up there now doing Earth imaging. By the year 2001, or 2002 I guess, about another 40 total satellites will be collecting images of the Earth. But we don't do that as a threat to you. I should say a threat to us. Because we feel that we're a part of your team now. We've gone from the history of closed skies [to one of more open skies].

Here's what we can find on the Internet now—just a couple of clicks away. The Sputnik launch site. A comparison of the early satellite, or the early spy imaging with SPOT—missiles in Cuba. The second-to-the-latest keyhole spy satellite launched by the U.S. We're moving now to a condition of transparency—open skies. This is in debate. It's in debate in the literature. If any of you are interested, I have some papers and some articles that I might refer you to. But basically we're moving to where we can get an image of Bosnia in some detail that shows the damage done by bombs, etc., and also literally an image of people moving away. So we're moving in that direction rapidly.

We've gone from 30 years in older-satellite 30-meter resolution—80 meter when we started with the early Landsat to 30 to 20 meters to 10 for SPOT Pan, to 5 for the Indian satellite, and now 1 meter with an IKONOS. An IKONOS first image, incidentally, is out on the Web. You can pick it up by dialing in to [www.spaceimaging.com](http://www.spaceimaging.com) and download it yourself. It's about a gigabyte. It's a biggie. It's of Washington, D.C., but it's a beautiful image. That's what we're trying to achieve as well with the ERAST images.

What I do want to point out is one of the major deficiencies in the data that we now have available to us—and that is the frequency of coverage. We need much more frequent coverage. We need continuous coverage over a disaster site and agricultural areas, and, of course, the continuous operation for telecommunications. So that's where our needs are.

What I wanted to do also is give you a feel for what some of these images look like and how you can project ahead and see what we might be able to attain.

The first image that the Russians announced that they took of us—you'll all recognize it. It was taken back in the '50's. The images that we took for General Schwarzkopf—Earth Satellite Corporation in three days produced 20,000 copies of multiple images for the Gulf War because General Schwarzkopf couldn't use the soda straws of spy satellites because he needed to see the whole picture. So that was done.

There are also the first images, the one that we had of Kobe—that earthquake—and then the first image of Chernobyl. If you look at these carefully, you'll see that you can't see much. Because these are low-resolution satellite images that will enable you to cover an entire territory: the entire watershed of the Mississippi drainage, for example, 26 Landsat scenes mosaic together. But we needed more detail. So as we went into that study, we compared pre-flood conditions on the Mississippi in '93 with the then-peak

flood conditions. We used radar as a collateral data source. But even there we had very little data. We had to select scenes that were as long as 60 days away from the peak flood in order to try to calculate the peak flood.

Change detection. We look at places like the Caspian Sea and marvel at the fact that the Caspian Sea's level goes up and down dramatically. Now we have data that goes back over the years. This is low-resolution data, but it's very useful in giving us some idea of what's happening there. The only place in the entire Mississippi during that flood of '93, where we had sequential data that could have been obtained by an ERAST vehicle in all of the area of the Mississippi flooding, was in a small area on the Missouri River. This [slide] is before. This [slide] is at peak flood. When we look at this, look at about the center line of this. That's about 20 kilometers across. The river itself is maybe maximum of a half [of] a kilometer in that position. Then, a month after the peak flood.

In addition, we've used change detection. And this, of course, is an ideal use of these aircraft for flood-related work and relating that to FEMA's flood zones, to the building of properties, and so forth. And as you look at these as they come by, it will show you where insurance claims are, where claims are outside of the flood zone. Why are they outside of the flood zone? Maybe it's a fraudulent claim. So that is now being investigated.

We look all over the world. We can use low-resolution satellite images to cover all of Asia or the whole of Bangladesh or Saudi Arabia where we get the whole picture. Or we can go to places that are difficult to get to—Olduvai Gorge, for example, and Ngorongoro Crater.

Here's where we're going. With the equivalent of imaging that is as good as or better than aerial photography taken by the standard aerial photographic means, imagery that is as good as or better than the spy satellites or the ones taken by the SR-71 over Vietnam, for example. Imagery in which data can be extracted automatically because the evolution of image processing is taking place at a very rapid pace. We are now able to take an image like this one of West Sacramento and automatically extract a digital file, a vector file from that image.

The technology is evolving both up in the air and on the ground. I would offer the assistance of risk management solutions and our subsidiary for any assistance you folks might need. We welcome the fact that we've been asked to participate.

Jenny Baer-Riedhardt: Our next speaker is Professor Stan [Stanley R.] Herwitz. He is the current Professor of Biogeography and Earth Science at Clark University [Worcester, Massachusetts]. He specializes in airborne remote sensing and 3-D modeling of light interception in tropical rain forest canopies.

Stan Herwitz: [From File Provided by Speaker]

Title of presentation: "Coffee harvest optimization using UAV platforms for the acquisition of high-resolution multispectral imagery."

Coffee is the largest agricultural commodity traded on world markets. Hawaii provides rich fertile soils and a very favorable climatic regime for coffee and many other tropical crops. Historically, Hawaii's two dominant crops have been sugarcane and pineapple. However, economic factors have led to their recent decline. Coffee has been the primary replacement crop. Traditionally, Hawaiian coffee has been grown on small farms averaging about 3 acres in aerial extent, with few farms exceeding 50 acres. Hawaii's Kona Coffee, for example, is from 600 independent small farms. On land previously used for

sugarcane, the conversion to coffee has been on plantations exceeding 1,000 acres. The fundamental difference between these two scales of production is that on small farms the coffee cherries are hand-picked, while on large plantations, such as the Kauai Coffee Company's (KCC) 3,600 acre Koloa Estate, the coffee cherries are being mechanically harvested (Fig. 1).



Figure 1. Fleet of mechanical harvesters in operation on the Kauai Coffee Company's 3,600 acre plantation.

The mechanical harvester used by the Kauai Coffee Company passes over each row of coffee trees with an array of slowly rotating spokes (Fig. 2). These "dynarotors" shake the ripening cherries onto a conveyor belt assembly that leads to large capacity side loader bins. The main limitation of mechanical harvesting is the inability of the harvester to discriminate between ripe, unripe, and overripe cherries. No coffee field or row ripens synchronously nor do the cherries on an individual coffee tree. As a result, any cherry-bearing tree that is shaken vigorously during the four to six week harvest season will contribute cherries in different stages of ripening. All harvested cherries are of some commercial value, and the Kauai Coffee Company sorts their harvested ripe, unripe and overripe cherries using a system of water baths; however, it is the ripest cherries that have the highest commercial value. To maximize the annual harvest of ripe cherries, the daily challenge for any large scale mechanical harvesting operation is to harvest those sections of the plantation having the highest percentage of ripe cherries.

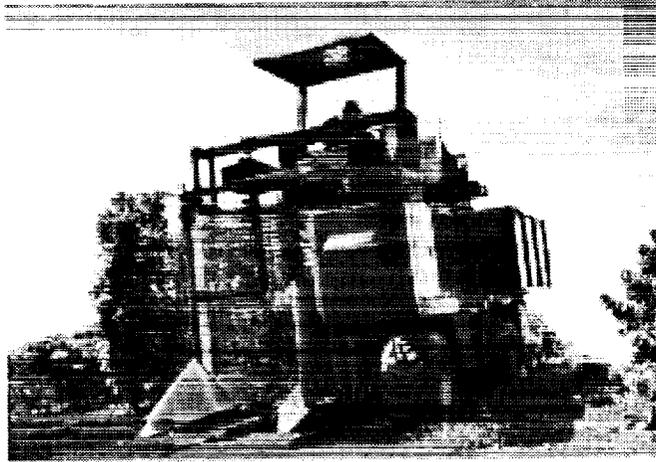


Figure 2. Close-up view of a mechanical harvester. Note the dynarotors and side loader bin.

Of the five million pounds of coffee cherries harvested annually by the Kauai Coffee Company, only about 30 percent are ripe; the other 70 percent are unripe or overripe. It would never be possible to mechanically harvest 100 percent ripe cherries because of the variation in the timing of coffee cherry ripening. However, if the percentage of harvested ripe cherries could be increased by only ten percent annually, there would be a substantial increase in revenue. Ripe cherries are worth about two dollars per pound more than unripe or overripe cherries. Therefore, if there was an increase from 30 percent to 40 percent of harvested ripe cherries, then the additional 500 thousand pounds of ripe cherries would represent an additional one million dollars of revenue.

The question is: how will this increase in the annual harvest of ripe cherries be achieved? The answer is by using UAVs as platforms for acquiring high-resolution airborne imagery during the harvest season. The timing of this NASA ERAST Exclusive Preview in October coincides with coffee harvesting in Hawaii. The Kauai Coffee Company mechanical harvesters are being dispatched, as we speak, to selected fields in the Koloa Estate based on small samples of branch clippings. The cherries on each sampled branch clipping are sorted by color and grouped for the determination of percentage ripe, unripe and overripe cherries in the corresponding field. The Koloa Estate consists of several hundred fields, and it is simply not possible for this branch sampling approach to provide a spatially integrated and temporally synchronous assessment of each field's state of ripeness. The unpredictability and the spatial and temporal complexity of coffee tree ripening needs an integrated airborne perspective. We envision defining the spectral reflectance signatures of ripe, unripe and overripe fields, and then using recent advances in the real-time transfer of airborne imagery to the operations managers who are responsible for the scheduling of the mechanical harvesters. To understand why UAVs would serve as the most useful platform, we need to first review the structure of a coffee canopy.

During the harvest season, a ripening field is an assemblage of dark green leaves interspersed with clusters of non-pendulous cherries borne directly on woody shoots. As the cherries ripen, they enlarge and change color from green to yellow. This color change corresponds to the main variety of Coffee Arabica grown on the Koloa Estate. The challenge is detecting this change using airborne imagery. As an ERAST Science Team Member of the Pathfinder Hawaii Mission in 1997-1998, I defined a series of flight lines over the Kauai Coffee Company plantation, and imagery was acquired by ARTIS (Airborne Real-Time Imaging System). ARTIS, which was part of the Pathfinder payload, consists of a Nikon

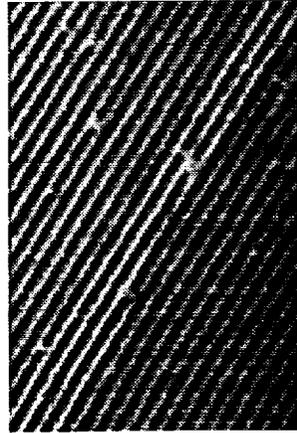


Figure 3. ARTIS view of neighboring coffee tree rows in March 1998, with the unusually bright rows corresponding to asynchronous flowering.

camera body with interchangeable lenses attached to a high-resolution Kodak color infrared digital camera. In March 1998, the FAA restricted the use of Pathfinder over populated areas. Over the Kauai Coffee Company plantation, a piloted Piper aircraft was used as a surrogate platform. My analysis of the high-resolution ARTIS imagery revealed the location of several unexpected anomalies defined by subsequent ground-truthing. Coffee tree rows exhibiting unusually low reflectance in the infrared waveband were found to be infested with a black sooty fungal mold that had proliferated on leaf surfaces in response to honeydew secretions from green scale insects. A distinctive multiband signature was found to correspond to localized patches of spreading vines that often climb and envelop coffee trees, complicating the operation of the dynarotors during the harvest season. The most striking anomaly was a set of neighboring coffee tree rows exhibiting unusually high reflectance in the red and green wavebands corresponding to asynchronous flowering in response to a localized failure in the Kauai Coffee Company's drip irrigation system (Fig. 3). It was this detection of flowering in a well foliated coffee tree canopy that led to our interest in the airborne detection of coffee cherry ripening.

If the flowers of coffee trees can be seen, then the cherries also can be seen. The cherries are of the same size as the flowers and they are located in the same position in the canopy. Recognizing the possibility that coffee cherries may be detectable from an airborne perspective, my colleague Professor Barry Ganapol of the University of Arizona and I applied a radioactive transfer model to a coffee canopy. The model simulates the processes of photon scattering and absorption within a heterogeneous canopy in which green leaves interspersed with clusters of small fruiting bodies were represented by a complex array of optical elements. Ripening was simulated by gradually changing the color of the cherries from green to bright yellow. The model predicted that a considerable proportion of canopy reflectance received by a digital imaging system such as ARTIS would consist of spectral noise and that only a narrow set of wavelengths would reflect coffee cherry ripening. In an effort to resolve the ripening signal, we plan to test a series of customized narrow waveband filters. The objective is to discriminate between fields with different percentages of ripe cherries. Real-time image transfer would assist operations managers of large coffee plantations such as Kauai Coffee Company's Koloa Estate in coping with the unpredictability of coffee field ripening. Some fields exhibit sudden pulses of rapid ripening, while other fields may ripen at exceedingly slow rates. Most confounding is the fact that these fields do not exhibit the same predictable behavior over successive years.

Tomorrow I fly to Hawaii to conduct a series of ground-based multispectral measurements directly above the canopies of ripening coffee fields using a portable spectroradiometer and test our predictive model. Harvesting has been in progress on the Koloa Estate since October 1st. The week of peak harvesting is expected to begin this Monday on October 18th. At that time, the mechanical harvesters, which are equipped with headlights, will be operating 24 hours per day. Measurements will be conducted above selected fields during near midday daylight hours immediately before and after they are harvested. Our spectral reflectance measurements will then be compared with the actual percentage of ripe cherries collected in the harvester's side loader bins. We are predicting a strong correlation. Upon completion of this ground phase in which the spectral signatures of ripe, unripe and overripe fields will be defined, we will be ready to proceed with our airborne efforts.

The UAV platform must maintain a high level of aerodynamic stability, minimizing vibrations and insuring that the digital sensor maintains a nadir view. Slow flight speeds with an ability to linger over areas of interest is the key characteristic of the UAV platform needed to acquire high-resolution airborne imagery of narrow wavebands. The digital image acquisition unit that we propose to use is called ALFI (Airborne Large Format Imager) (Fig. 4). ALFI is a high-resolution Daedalus digital camera equipped with a filter wheel that rotates in quick succession. The result is a series of spectral images that are co-registered using a special software module. The slower the flight speeds, the more reliable is the co-registration. A lingering UAV characterized by slow flight speeds will enable us to test a set of customized filters for the determination of those narrow wavebands most strongly correlated with field ripeness. Examining such narrow sections of the spectrum in an effort to eliminate spectral noise, it will be necessary to open the camera shutter for longer exposure times. And if the shutter is held open longer, slow flight speeds must be maintained to insure that the imagery is not blurred by aircraft motion. Another criterion for selecting a UAV will be its ability to accommodate the greater weight, the ALFI payload (125 pounds) compared to ARTIS (29 pounds). The reason for using ALFI, rather than ARTIS, is to take advantage of its filter wheel capabilities. ALFI will serve as a tool for defining the specific wavelengths that provide the most accurate spectral signatures of field ripening.

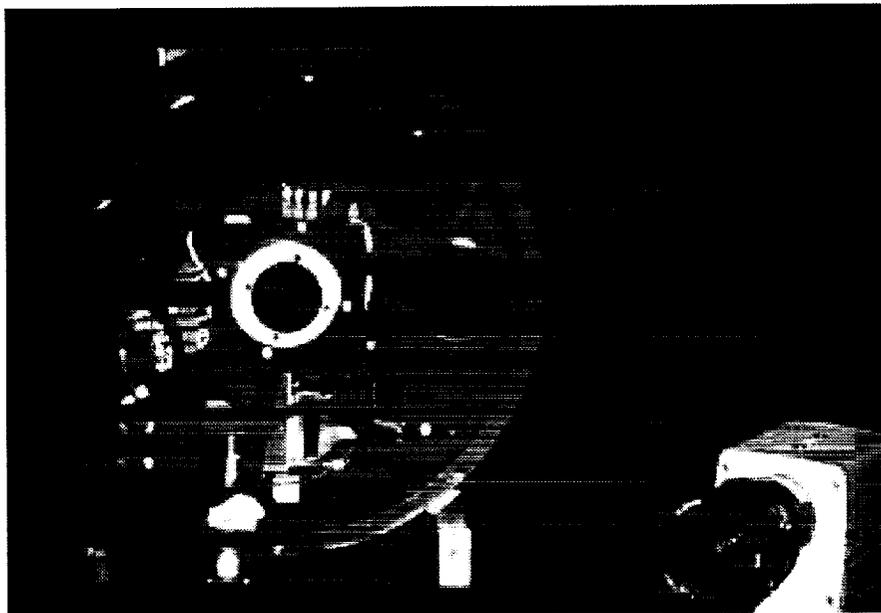


Figure 4. View of ALFI with protective base plate removed to show the rotating filter wheel and the detached digital camera.

A digital camera is the desired payload because of its ability to generate views of the plantation recognizable by the coffee operations managers. A complex array of spectral graphs would not be useful for real-time decision-making, particularly as it relates to the location of the ripest fields. The acquired imagery will be transferred in real-time to the office of harvest operations. High-resolution airborne imagery covering their entire plantation will appear on their computer screens. Once we establish the spectral threshold for ripening, those fields with the highest percentage of ripe cherries will start flashing and the harvesters will be promptly dispatched. The cost of the UAV platform will be a relatively small percentage of the increase in revenue generated by the 10–15 percent increase in the annual harvest of ripe cherries.

Establishing partnerships involving NASA, universities, and commercial business interests is a well-defined NASA objective. Technological advances such as UAVs need to be introduced to the business world in order to contribute to the betterment of the US economy. If our optimization of coffee harvests is successful using UAV technology, the state of Hawaii will be a major beneficiary. Hawaii faces some serious challenges in commercial agriculture over the next decade. The Kauai Coffee Company is not the only company pursuing large-scale coffee production. We hope to assist all companies that plan to convert sugarcane and pineapple to large-scale coffee production. Strategically joining the new technologies of UAVs, real-time digital image transfer and mechanical harvesting, we hope to contribute to the revitalization of the Hawaiian economy.

Jenny Baer-Riedhardt: Thank you very much, Stan. Our next speaker is Gary Darling. He's the Chief Information Technology Officer for the California Resources Agency. He's also the Director of the California Environmental Resources Evaluation System.

Gary Darling: [Slides unavailable] There's one thing that someone asked me to add that I think was meritorious but I didn't get in. And that's: What is the Resources Agency? We assume that in California you will have heard of us. But the answer is that often people have not heard of the agency, but you have heard of our constituent departments. The Resources Agency is only ten professional staff. But there are 16,000 people in our constituent departments. Those include the Department of Water Resources, Fish and Game, Parks and Rec, the Department of Conservation, and all 19 departments, boards, commissions and programs. We also have the conservancies—the Tahoe Conservancy and the Coastal Commission within Resources Agency. We're a thin coordination line. That's kind of a tricky position to be in when we start working with technology, because there are so few staff in the agency that we're dependent on going into the departments and looking for value.

One of the things that was pointed out to me just as I was about to start this talk is that California already owns a remotely piloted vehicle. It can hover for up to ten hours. We're getting very good resolution. We can resolve 100 centimeters often from it. We're using it for monitoring individual species. It's serving us well off the north coast. We're able to monitor abalone populations and starfish and the like. Remarkably, this was very useful in explaining to the agency why remotely piloted, as we say in our infancy, unstaffed autonomous vehicles are useful.

Well, I want to couch this more in what's going on in California so you have a sense of what's happening in this state as this technology is advancing. Our population's just exploding. And that's putting huge pressure on our ecosystems. Voters in California are about to make some very critical decisions. There's going to be a park bond on the year 2000 ballot and a water bond—\$4 billion in your investment. It's the largest natural resources bond in history. And this is happening because California has not put a whole lot of money on the table in capital infrastructure in a long time. From the 1960's through the 1990's you can see that our share of investment's just been declining and bottoming out. And

this is a time that we really have to make a decision whether or not we're going to save the remaining ecosystems and build back up our infrastructure.

If Californians decide to increase the infrastructure investment, how are we going to use those funds efficiently? This is a quotation from a report that's just come out that's getting quite a bit of a press—the continuing study for California economy. It points out that a family or a business wouldn't make decisions based on the paucity of information that we now have. We don't have a lot of information on what infrastructure needs are and we need to make that a goal. Good decisions take good information. Some of the things that we're going to need if the bond acts come through is, we're going to have to enhance our data systems and geographic information, federated databases, mathematical modeling and remote sensing. UAVs are in a sense at the right place at the right time in California. They're a powerful and an efficient information source, and the information will be timely and gathered as needed.

This is a slide NASA provided me. I think it's a good picture of where we're trying to go. You see the growth in the Bay area from 1850 to the 1990's, and we're trying to set up an appropriate State/NASA partnership to move forward in this technology.

Now I wanted to stop and give an ad for one project that we already have going that we think has a lot of potential. This is a NASA, Resources Agency, Governor's Office of Emergency Services, and University of California project to take EOS [Earth Observing System] data and get it into the hands of the public, to distribute a GIS [Geographic Information Systems] system with imagery added in. This is going to be important in the long run as we develop geo-spatial data in California.

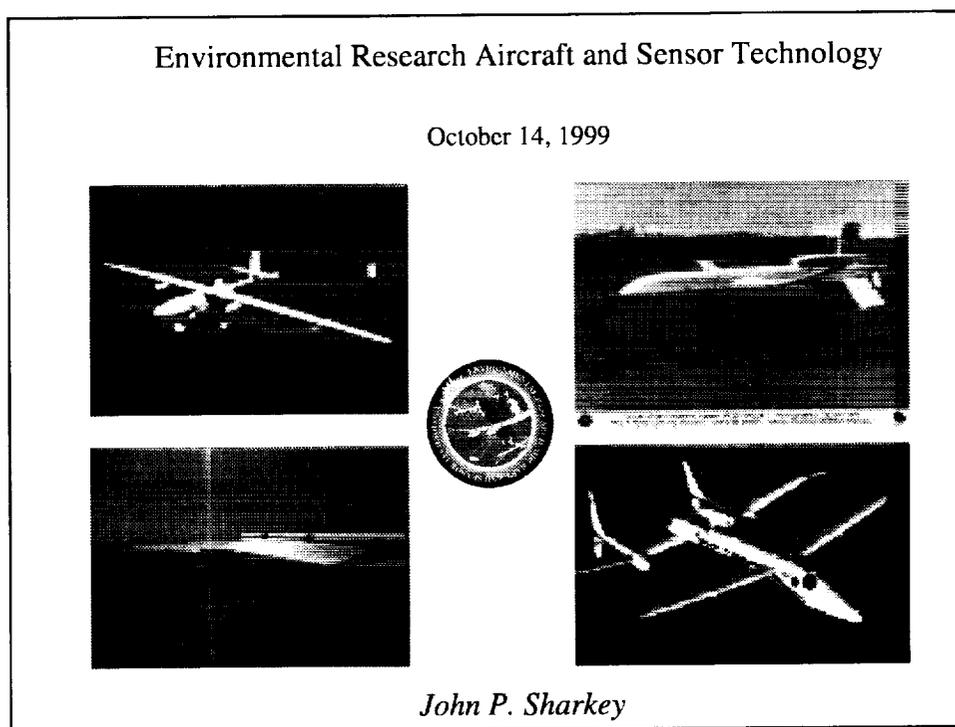
There're lots of advantages to going into un-staffed autonomous vehicles. I think the most important here is leveraging technology between NASA and California programs. One of the really nice things about the way particularly Ameritech has come to the State is a commercial entity has come to us and said, "Well, you're going to be the end customer, what product do you need?" and has helped facilitate things with NASA. That's the first time we've been approached this way. That's really been a good approach to commercialization. Usually what happens is after the fact we have completed products that are presented to us. And we'll often say, "No, we really can't use anything like that." This time we've been in the loop a lot more. And I think that's going to be a great boon in terms of California, NASA and Ameritech's success.

Now the benefits [are] to the California Resources Agency, or more broadly, to the State of California. I'm going to talk about a few that I think are the most important. After awhile working in state government you feel like you're on a first name basis with the four horsemen of the apocalypse. Everything goes wrong here. We have earthquakes and floods and fires. And we've had big ones. We're looking at a few potential events that could be just devastating. We pay a lot of attention to emergency services. Certainly this new technology has a lot of potential advantages. Sometimes the smoke is so heavy over a forest fire we really can't deploy our resources very well. In floods it's hard to get a handle on flood perimeter. And the synthetic aperture radar payload would let us get a sense of where the flood waters are. Communication for California after a big seismic event would be critically important. In emergency services, this is plainly quite useful. Also in water ship management, data for geographic information systems. Something that I find particularly personally interesting. Under the California Environmental Quality Act you don't have to do an EIR [Environmental Impact Report] if you're doing something that doesn't have a substantive impact. But you could fill in the entire central valley of California house by house without ever writing an EIR. Because you're not in any individual action taking a suppletive thing. There's no notion of cumulative impact as equal as it now stands.

This technology would let us monitor the entire valley at once. We'd have the initial property rights to the image, which is something most of the time we don't have. And it's a requirement under the Public Records Act that we be able to give what we use for information—the information we use for decisions to the public. This time we'd be able to get the image, give it to the public under the Public Records Act, and make decisions based on what we saw. That's kind of unprecedented. That's not been true in the past.

Let me finish up in this way. I think one of the things that's playing here is that the aerospace industry really has a very great opportunity to help the environment, to help business, and to do it in a very important way starting in your own backyard. As I was walking out talking to the public information officer for our Agency about what was going to be said today, he said, "You know, stress to everyone that they're, in a sense, doing God's work." This is very important stuff to do right now in California. It's information that we really need to manage natural resources in. I want to compliment all of you on the good work that you've done. We're very excited about the potential effect of what could come forth here.

Jenny Baer-Riedhardt: I'd like to go ahead and reintroduce John Sharkey. He's the Program Manager of the ERAST Program right now.



John Sharkey: One of the things we wanted to do at the Plenary Session is cover some of the common topics, and then we can break up and go to the workshops. This morning we saw demonstrations of Helios and Proteus. But I wanted to just go through quickly our suite of aircraft one more time in case there are any questions or comments to cover the aircraft prior to the workshops.

We did not get a chance to see Altus flying today. You saw it down in the hangar today—the General Atomics vehicle. We have flown just in this past year, 47 flights of Altus, from June of '98 to July of this year. This year we achieved 50,000 feet for 8 hours and 55,000 feet for 4 hours. So that demonstrates the current capabilities of one of our reciprocating-engine aircraft.

## Topics of Discussion

- Summary of Current Capabilities
- Overview of Future Capabilities
- ERAST UAV Deployment Guidelines
- Acknowledgements

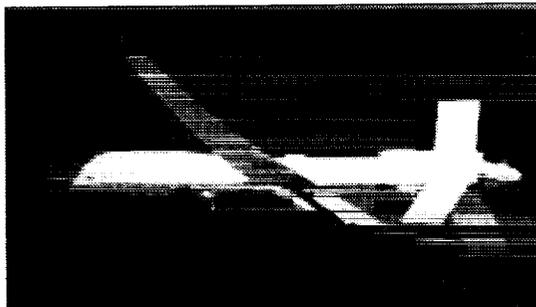


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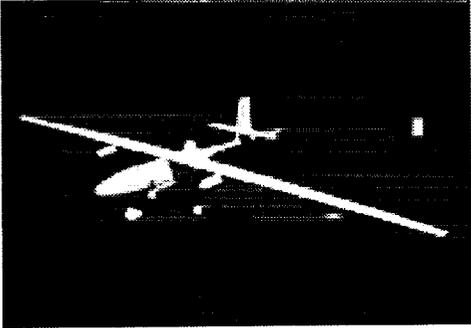
## Altus DT Description

**Owner:** General Atomics/ASI and NASA  
**Manufacturer:** General Atomics/ASI  
**Where Operated:** El Mirage, CA w/chase; EAFB, and PMRF  
**Flight Safety:** General Atomics/ASI  
**Air Worthiness:** General Atomics/ASI  
**Range Safety:** GA/ASI; DFRC  
**Wing span:** 55 ft  
**Fuselage length:** 24 ft  
**Wing area:** 131 ft<sup>2</sup>  
**Aspect ratio:** 24  
**Take off weight:** 2250 lb  
**Payload:** 330 lb  
**Altitude:** 65,000 ft  
**Airspeed:** 70 kts cruise; 100 Vne  
**Endurance:** 30 hrs max; 8 hr @ 50k  
**Structure:** Composite Construction  
**Engine:** Rotax 914 EFI with twin turbos  
**Engine Hp:** 100 Hp  
**Propeller:** 8.2 ft diameter      **Radius:** 400 mi



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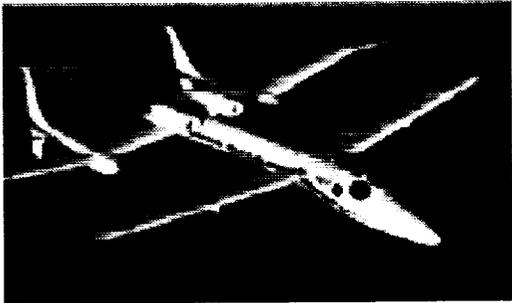


<b>Owner:</b>	Aurora Flight Sciences Corp.	
<b>Manufacturer:</b>	Aurora Flight Sciences Corp.	
<b>Where Operated:</b>	Dryden/Edwards Air Force Base	
<b>Flight Safety:</b>	Aurora Flight Sciences Corp.	
<b>Air Worthiness:</b>	Aurora Flight Sciences Corp.	
<b>Range Safety:</b>	NASA Dryden	
<b>Fuselage length:</b>	25 ft	
<b>Wing area:</b>	194 ft <sup>2</sup>	
<b>Wing span:</b>	71.5 ft	
<b>Aspect ratio:</b>	26:1	
<b>Take off weight:</b>	2450 lbs	
<b>Payload:</b>	176 lbs	
<b>Altitude:</b>	65,000 ft	
<b>Airspeed:</b>	52 KIAS cruise; 69 KIAS Vne	
<b>Endurance:</b>	7 hrs at 60,000' with 80 kg payload	
<b>Structure:</b>	Graphite epoxy, nomex honeycomb and kevlar aero surfaces, tubular steel frame fuselage	
<b>Engine:</b>	Rotax 914 horizontally opposed 4 cylinder modified to operate with triple stage turbocharging	
<b>Engine Hp:</b>	100 Hp @ 60,000'	<b>Radius:</b> 60 nm without Over-The-Horizon command & control
<b>Propeller:</b>	8.9 ft diameter	

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And then Perseus B is the other consumable-fuel aircraft—reciprocating-engine aircraft. Both of these aircraft are using that Rotax engine with a turbo charge, and that gets us up to altitude. Perseus B is designed for 65,000 feet just like Altus is. And for eight hours—this year we plan to do flight test for eight hours at 60,000 feet. Both of those aircraft fly in that 70-knots regime up at altitude.

### Proteus RPV Description

<b>Owner:</b>	Scaled Composites	
<b>Manufacturer:</b>	Scaled Composites	
<b>Where Operated:</b>	Mojave Airport, CA	
<b>Flight Safety:</b>	Scaled Composites	
<b>Air Worthiness:</b>	Scaled Composites	
<b>Range Safety:</b>	Scaled Composites	
<b>Wing span:</b>	77.6 ft	
<b>Fuselage length:</b>	56.3 ft	
<b>Wing area:</b>	131 ft <sup>2</sup>	
<b>Aspect ratio:</b>	24	
<b>Take off weight:</b>	15,800 lb	
<b>Payload:</b>	4400 lb	
<b>Altitude:</b>	65,000 ft	
<b>Airspeed:</b>	280 KTAS @ 40,000'	
<b>Endurance:</b>	15.3 hrs	
<b>Structure:</b>	Composite Construction	
<b>Engine:</b>	Williams FJ-422	
<b>Engine Hp:</b>	100 Hp	

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We heard pretty much the discussion this morning on the Proteus. Proteus is flown today. It is piloted, but we're working with Scaled Composites to develop the remote pilot capability for these vehicles.

### Solar Powered Helios Prototype Description

**Participants:** NASA Dryden & AeroVironment, Inc.

**Take off weight:** 1734 lbs

**Length:** 16.5 ft

**Wing span:** 247 ft

**Altitude:** 50,000 - 80,000 ft

**Airspeed:** 52 kts TAS @ 60,000'

**Payload:** 100 lbs and 400 watts

**Endurance:** 3 months design req't

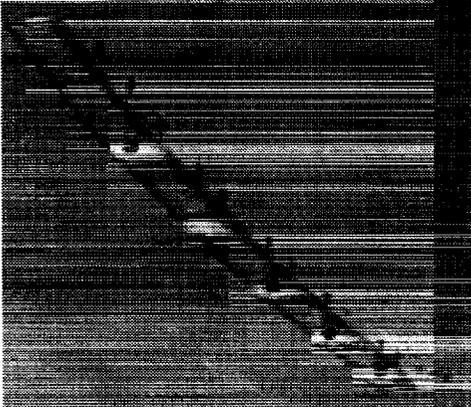
**Structure:** Composite

**Engine:** 8 Electric Motors (2 hp ea)

**Propeller:** 6 ft diameter

**Power:** 33 kw solar cell arrays

**Energy Storage:** 600 w-hr/kg fuel cells



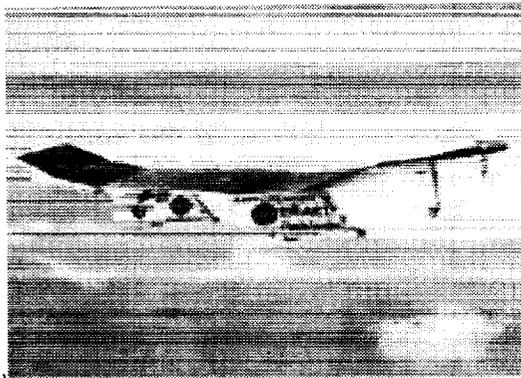
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You saw outside in the hangar today, and in the flight, the Helios aircraft. What we saw flying today was the 14-engine configuration. Later on this year and next month we'll be flying the eight-engine configuration, which represents the 100 hour mission for Helios.

## Solar Powered PathFinder Plus Description

**Participants:** NASA Dryden & AeroVironment, Inc.  
**Take off weight:** 700 lbs  
**Length:** 12 ft  
**Wing span:** 121 ft  
**Altitude:** 50,000 - 80,000 ft  
**Airspeed:** 17-21 mph cruise (IAS)  
**Payload:** 100 lbs and 400 watts  
**Endurance:** 15 hrs in daylight  
**Structure:** Composite  
**Engine:** 8 Electric Motors (2 hp ea)  
**Propeller:** 6 ft diameter  
**Power:** 12 kw solar cell arrays  
**Energy Storage:** Lithium battery packs (3 hrs)



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The Pathfinder is available to do missions today to support any proposals or concepts—flight demonstration concepts that might support the discussions we had earlier today. That's the current suite of aircraft.

ERAST UAV Platforms		Perseus B	Altus	Proteus	Helios Prototype
<b>Code Y Science Requirements</b>					
Payload Field-of-View:	Unobstructed Access to free airstream	Yes	Yes	Yes	Yes
Payload Pwr:	3kW @ 28 VDC	2kW @ 28 VDC	3kW @ 28VDC	19kW @ 28VDC	1000 Watts @ 28 VDC & 3kW during day
Payload Mass:	300-400kg	150kg max	150 kg max	Up to 2000 kg	100kg max
Primary Altitude:	40k-to-65k feet	Yes	Yes	Yes	Yes
Mission Endurance:	24-to-48 hr. with 300kg min. payload @ the primary Mission alt.	Up to 65k 24hr @ 75 ft alt 7hr @ 65k ft alt With 30kg payload	Up to 65k 10hr @ 50k 1hr @ 60k 1.5hr @ 30k 8 hrs payload	Up to 53k 15.8 hrs 22 hrs with Aux. Tanks	50K'-70K' 100kg Payload: 6 months @ 50-70K'
Airspeed:	N/A	52 kts cruise	70 kias	280 KTAS @ 40,000'	19-25 mph (IAS)
Range:	N/A	1600 nm	1000 nm	3000 nm	1,000,000 nm!!!

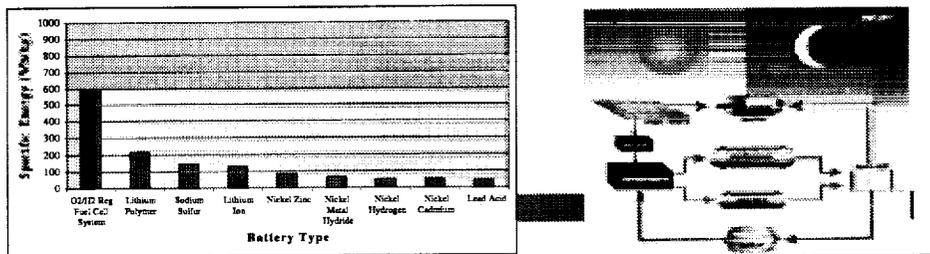


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## Future ERAST Project Objectives

- Develop very high altitude solar power UAV technology by demonstrating flight capability above 100,000 feet
- Develop extreme duration solar power UAV technology by demonstrating sustained flight capability above 50,000' for more than 96 hours
- Develop ERAST consumable fuel UAV technologies by demonstrating flight operations and capabilities that exceed the minimum Code Y science requirements.



We have three main program objectives for ERAST in the immediate future. One is to continue the solar aircraft program to achieve the 100,000-foot objective. The second one is to demonstrate the extreme long-duration capability by demonstrating the Helios flying for 96 hours or more above 50,000 feet. Now in order to do that, the key feature here is what Ray Morgan discussed—the energy storage system that's shown on the right. That energy storage system is a regenerative fuel cell that takes the excess solar energy during the daytime and decomposes water into hydrogen and oxygen. In the nighttime it converts it back into electricity. To do that, the scale on the right shows the regenerative fuel cell. Our target is to reach 600 watt-hours per kilogram as an energy storage device. That's like three times better than the best state-of-the-art batteries available today.

Those are two of our main objectives over the next four years. And then finally, we are going to develop one additional platform under ERAST. That's going to be a next-generation science platform that's being designed explicitly to meet the Code Y [Earth Science] science requirements, and that is 24 to 48 hours at 40,000 to 65,000 feet with payloads of 300 to 400 kilograms. So that would be between now and FY-02. In the three years we'll demonstrate that capability.

Now I want to give you a couple of planning guidelines just to follow up some of the discussions we had here on potential uses. From our recent experience—this is just from my perspective and just something to get on the table, something we can talk about—when we do a deployment, there are some fixed costs. So I want to give you some parameters, both cost-wise and time-wise, on where we are today to go to conduct a mission. If we want to do demonstration flights, there are \$250,000 to \$500,000 of fixed costs up front to do experiment planning, integration, and to deploy. Once we get deployed, that will run something like \$250,000 a month to conduct these flights. Some other items underneath that. One of the major cost drivers is hull insurance for the vehicles at this time. It's a significant cost driver. As we get more and more uses out of the vehicles and more flight time demonstrating the liability, insurance costs will go down and make it more affordable to the rest of the community.

## Planning Guidelines for ERAST UAV Deployments

- \$250K-\$500K fixed cost for deployment (location dependent)
- \$250K/month for operating costs
  - Crew of 3-7 for consumable fuel UAV
  - Crew of 10-15 for solar powered UAV
  - UAV hull insurance comprises 40%-60% costs
    - Insurance costs will decrease as UAV utilization increases
  - Operating costs do not include capital costs or depreciation
- Acquisition costs of UAV aircraft alone
  - Without Ground Control Station, training or operations
  - \$2 - \$3M for reciprocating engine UAV's (Altus, Perseus)
  - \$3 - \$5M for solar powered Helios
  - \$10-\$12M for Proteus

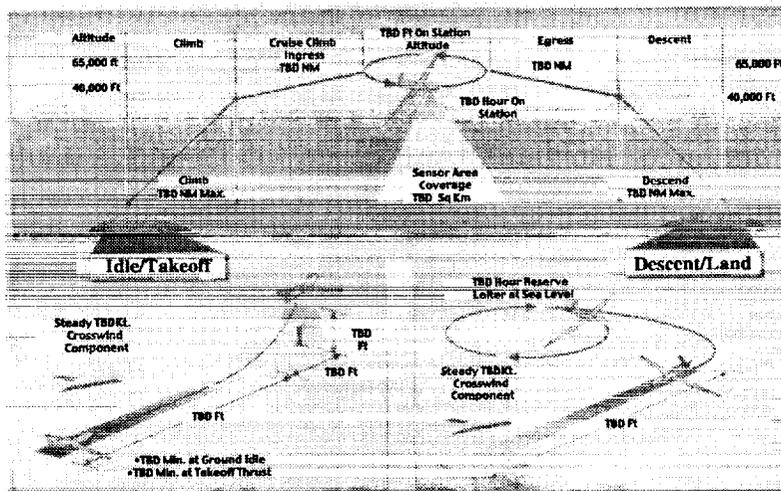


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Then on the next board, this is just my guess to the companies on what acquisition costs could be for these vehicles. Without providing ground-control stations, training or operations—just the vehicles themselves—you can see here we're talking about for the reciprocating engine aircraft \$2–\$3 million in ballpark prices; \$3–\$5 million for the solar powered aircraft; and for Proteus in this current configuration, something like \$10–\$12 million.

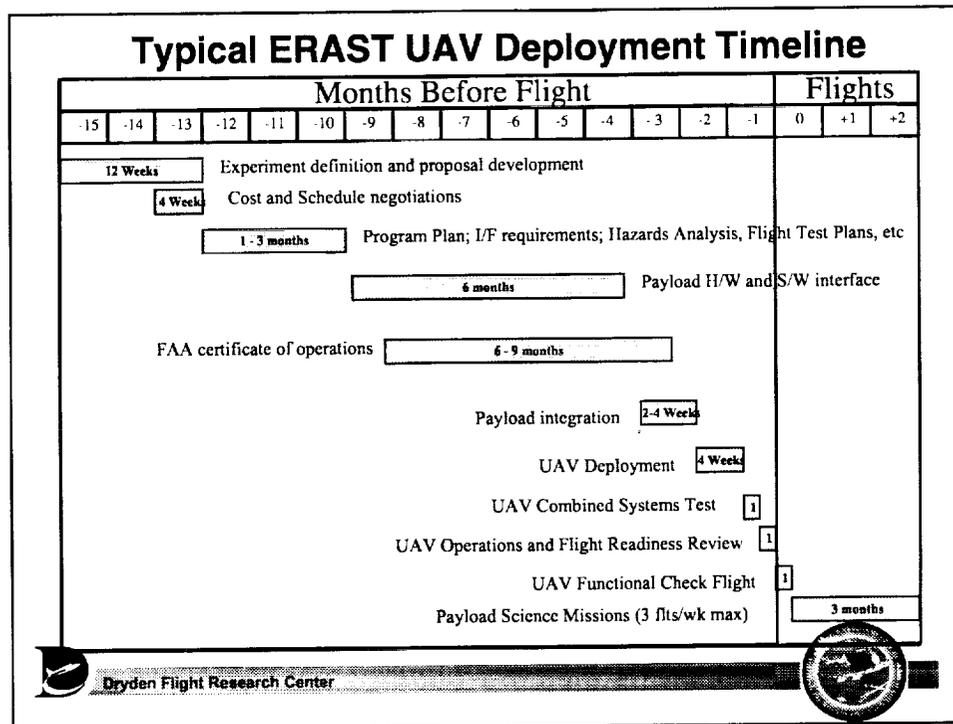
## Notational ERAST UAV Mission



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I just wanted to show you a notational science mission on how we might actually use one of these out in the field. This is actually an extract from current proposals that we have for the Code Y science platform. The point I want to make on this is that right now our vehicles, our prototypes, typically take off and land in restricted air space. That's the takeoff segment on the left hand side here. Once we get up above 40,000 feet, we can operate under radar control, and we no longer have to stay in restricted air space as long as we've pre-coordinated with the FAA. Again, we'll go do our mission up at altitudes of 40,000 to 65,000 feet. That can be done outside the range if we planned that with the FAA. But then when it descends, either you have to descend and land back inside controlled air space like Edwards Air Force Base or the Pacific Missile Range Facility in Hawaii, or you have to work with the FAA at a pre-determined site, spend a lot of time working with them, and actually when the aircraft gets down to 18,000 feet or so, have some means of meeting up with the airplane like the guys at General Atomics do. They provide a chase aircraft to meet the aircraft when it leaves Edwards Air Force Base and they fly it into El Mirage. So that's one other way to conduct these missions.



This is really a conservative time line just to give you another point of consideration on what it might take to pull off a flight. I've outlined a 15-month preparation from start to finish. It could be done in as few as three months, but it depends on the payload, where the deployment is, and how much coordination it takes. The big driver in that is six to nine months of planning with the FAA. I said the certificate of operations and that's not strictly correct. But that is just for ballpark purposes. The steps you'd have to go through is work out an experiment-definition proposal, work with the companies and probably use some cost sharing, perhaps with other payloads, to work out your cost and schedule negotiations. And then when you get down to flying, one month prior to flight there would be a deployment—do your combined system test, functional check flights at your site, and then go do typically a two- to three-month mission. I would expect three flights per week would be a maximum flight rate for these vehicles.

## Workshop Objectives

- Open dialogue between potential UAV users and providers
- Identify barriers to successful, and profitable, implementation
- Provide inputs to the ERAST Alliance (NASA and industry partners) on how best to invest in future UAV technology developments



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Now we're going to phase into doing the workshop activities. For the workshops, we're hoping to have some open dialogue between potential users and the UAV providers. We want to identify where we have significant barriers to the successful and/or profitable implementation of your uses, and we'd like to get inputs back from you on how we should best invest our technology dollars between now and the next five years to meet your needs.

## Acknowledgements

- Pete Jacobs
- AmTech: Karen Robbins, et al
- PACE: John Childress, Ronnie Boghosian, Alan Brown, et al
- Workshop Organizers: Dale Tietz and Steve Wegener
- Speakers and Presenters
- Alliance Members: AeroVironment, Aurora, General Atomics and Scaled Composites
- ERAST Project: Maria Tobin, John Del Frate, Dave Bushman



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I want to recognize Pete Jacobs because it's kind of his brainchild to have this event. He recognized the maturity of the platforms we have here. So it was between Pete Jacobs and Karen Robbins at Amtech. They really provided the genesis for having this event today. I also want to acknowledge John Childress, Ronnie Boghosian, and Alan Brown of Public Affairs, Commercialization, and Education (PACE), and a lot of other supporting players at PACE. But those are the folks I've been working with most directly over the past couple of months to pull this off. The workshop organizers—Dale Tietz and Steve Wegener— have put in a lot of effort to pull this together. I do want to thank all the speakers and the presenters who have taken their time to come out here and share their views and opinions on Unpiloted Aerial Vehicles (UAVs) and the ERAST Program with you—the alliance members working with us to pull off these flight demonstrations and displays in the hangars. It took a lot of effort to pull that off. And, in particular, on the ERAST Project itself, Maria Tobin was actually the person that pulled together the flight demonstrations today. We've never done two ERAST flights in the same day before. That was a kind of a risky venture for us. She deserves a lot of credit for pulling that off. In addition, John Del Frate has been with ERAST longer than anybody else in the project right now. John Del Frate and Dave Bushman are the ones that actually got those airplanes working with the companies and pulled off those flight demonstrations.

Question: It's on the insurance numbers that you had up there. You had 40 to 60 percent. Is that percent of replacement costs?

John Sharkey: No. I'm sorry. Of the operating costs. I showed a number of about \$250,000 a month to operate these vehicles. And the insurance can be a significant part. As much as 40 to 60 percent of your operating cost today is for hull insurance on your vehicle. That's because these are prototypes—one of a kind. So we have a lot of dollars invested in these prototypes. Right now that's a dominating cost. If people start buying these, those insurance costs will go down. But for these prototypes, insurance costs are dominant.

Question: Does that number you put up there apply primarily to the unmanned vehicles because they are unmanned and not necessarily to the manned.

John Sharkey: Yes. Thank you. Those numbers do not apply to the Proteus vehicle. Because that has pilots on board. That's more conventional and flies with conventional insurance. It's experimental, but it's not UAV.

Question: I had a question regarding the gentleman with the cocoa beans, or the coffee beans with Pathfinder. Stan, you mentioned that the Pathfinder was not able to fly over the coffee bean plantation because it was a restricted area? Could you expand a little bit on that?

Stan Herwitz: Well, from what I knew, in March of 1998 when the overpass was made of the plantation—the images you saw—it was restricted. That's just the way it was.

Question: Restricted because...

Stan Herwitz: It's a populated area.

Question: Okay. So that had not been worked out in advance with the FAA to allow that?

Stan Herwitz: No, it hadn't.

Question: Do you view that that's a critical issue?

Stan Herwitz: Yes, it is. It was a long procedure.

Question: My assumption was incorrect this morning that those issues could be worked through relatively easily.

Stan Herwitz: Yes, they can. Well, the flight demonstrations were helpful in that respect. They flew successfully. Obviously, there's opportunity now. I think the door is opening to proceed with lifting those restrictions.

Jenny Baer-Riedhardt: Let me go ahead and address that. Basically what we looked at doing was taking a stair-step approach. We did have a policy when we were doing the flight test work with the Pathfinder and also the Altus not to fly over populated areas. The airplanes were not allowed to fly over populated areas, which was part of the coffee bean fields and the plantations, because we could not get a good idea of where the people were in the population. We did have clearance to over fly other parts of the Island like Waimea Canyon and areas that were not a populated. We have worked and are continuing to work with the FAA and also with the states, looking at ways that we can demonstrate overflights of certain areas. We don't want to take that risk until we do get the reliability up with these vehicles. So that was the main reason.

John Sharkey: These were demonstration flights of the capability. We didn't necessarily want to spend that six to nine months working with the FAA just for that purpose. It's not necessarily preclusive that you can do that. But it takes effort and planning and coordination. That is one of our major challenges in front of us.

## **COMMERCIALIZATION WORKSHOP**

## COMMERCIALIZATION WORKSHOP

Dale Tietz: I have volunteered to chair this panel today. First, for the ERAST Program, we are looking at the potential commercial opportunities that may be out there for these fledgling aircraft. Most people realize we have a broad mixture of representatives here, some that follow the NASA programs and others come out of the Department of Defense and international programs.

Today is an opportunity for our briefers to give their views on what they perceive to be commercial opportunities in the marketplace. It is not meant to be all-inclusive. It is free form at this point. It's an opportunity, from a forum standpoint, to have an open discussion of what the prevailing thoughts are, to the extent that people are willing to discuss them in the marketplace.

I would like to introduce our first speaker, Mr. Basil Papadales. Basil is the president of Mirada, Inc. It's a business consulting firm out of Seattle. Basil comes with a rich background—rich history in robotic aircraft. He got his start in undersea warfare activities many years ago in the Pentagon in DARPA DoD programs. Most importantly, he was one of the early program managers for the formerly classified program called Condor. Basil then took various positions in industry, one of which was with Boeing, and today is in a private consulting firm or business development firm in Seattle. Basil is also a consultant with the ERAST Program and has been helping us with market analysis, market projections, etc. That's what he's going to relay to us.

### Commercial Opportunities for Low Cost High Altitude UAVs

prepared for the  
**ERAST UAV Commercialization Workshop**

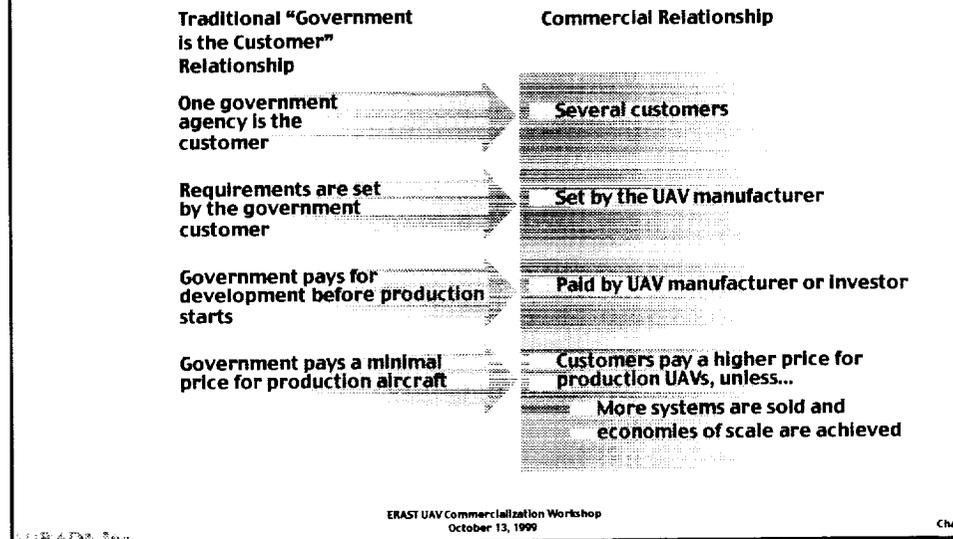
October 13, 1999

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B. H. & P. Inc.

Basil Papadales: Good afternoon. I'm going to give a brief overview of our company's view of commercial opportunities for a part of the UAV market that's of interest to the ERAST Program. We call that class of vehicle low-cost, high-altitude UAVs.

## Shifting to a Commercial UAV Market



We're going to talk about commercial opportunities. In the simplest way, there's a shift in the market. Today 98 percent of the UAV market is a "government as customer" paradigm. That means many things. There's generally one customer. The customer sets requirements. But the biggest difference is, compared to a commercial business activity, the government pays for development up front. Now that has some implications if you want to switch to the commercial business model. In the commercial business model, either private investment or the supplier itself pays for development at its own risk, and then recovers that cost in production. That presents an interesting problem: if you have a fixed market, that's not very good if you only have one customer, because that means the production price of that airplane is going to go up to cover the development cost and the cost capital. So the only way commercialization makes sense is if you commercialize and you somehow expand the market. That's what I'm going to talk about today: the opportunities to sell UAVs to people that historically have not bought them. That's the key to commercialization. In fact, in the entire UAV market there are probably only two or three segments where commercialization, at least right now, makes sense. This is one of them.

## The Projected Global UAV Market

	1998	2004
<b>Industry Revenues</b>	<b>\$2.1B</b>	<b>\$3.5B</b>
<b>US Share</b>	<b>45%</b>	<b>36%</b>
<b>Military Share</b>	<b>94%</b>	<b>96%</b>
<b>First Tier Suppliers</b>	<b>168</b>	<b>140</b>
<b>User Countries</b>	<b>45</b>	<b>55</b>

Constant 1998 US dollars  
Source: MIRADA Inc.

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Chart

This is the UAV market today. It's about a \$2 billion industry worldwide, and that's U.S. dollars. We project that in the next 5 years the industry is going to grow at a rate of about 8 percent a year. Now this is not all the money being spent on UAVs. This is the money being sent to contractors to keep the money flowing in the private industry. There is, in fact, about a 10 percent growth occurring in money that the U.S. Government's spending internally because more and more programs are now being activated, particularly on the military side.

There are some other parts of the market that I want to give you quickly. The U.S. market share has historically been for the last 5 or 6 years somewhere around half the global market. There's pretty much agreement that the U.S. market share is going to decline in the next few years, and that is because of increasing interest on the part of foreign countries, and particularly the military agencies, in buying UAVs. That interest has been developed primarily because of some of these small wars that have been fought recently—Kosovo being the most recent one that's stimulated a lot of interest in Europe. What that means is the market's growing, the U.S. share is declining, but the military share of that market is actually going up. The non-military share stays small—4 or 5 percent.

The other aspect of the market is it's highly fragmented in a sense that there are over 40 countries right now that use UAV's. We project that's going to increase by about 20 percent or so in the next 5 years. There are about 168 first-tier suppliers—those are companies that identify themselves as UAV developers, manufacturers, who will take money to go and put a UAV in operation for you. We expect to see some industry contraction, but not much. You have to really think about that from an economic standpoint. This is a \$2 billion global industry with 168 first-tier suppliers. I know of no other industry organized like that, certainly not in the high tech sectors.

## **The High Altitude UAV Market Segment**

### **\$140M in UAV industry revenues in 1998**

- **Primarily US military programs**
- **Projected annual growth of 9% through 2004**

### **Includes a \$28M niche for low cost high altitude (LCHA) UAVs**

- **Primarily civil government programs**
- **Potential for more than 20% annual growth over the next decade**

Source: MIRADA Inc.

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Chart

Within that market there's a high-altitude segment. That definition has changed over the years, but for convenience right now we define that as UAV's that will typically fly over 50,000 feet in altitude. In that market segment there's about \$140 million of that \$2 billion market being spent in the private industry. Most of that is in U.S. military programs. The part that isn't is primarily the ERAST Program. That niche that we call a low-cost niche; it represents about \$28 million. The ERAST Program is by far the largest part of that niche, which is all civil government. What are not NASA funds are from Department of Energy, and a few other agencies.

The key part to it—if you go through the UAV industry projections is that investment into private industry is going to increase at double-digit-type numbers—20 percent a year for the next 5, perhaps the next 10, years. That's why there's a commercialization opportunity. Now that number is projected not only on what people are planning to spend, but on what people could spend if the vehicles were there for them to buy. So it's what we call a demand number. It's what the demand for those vehicles will be if industry steps up to build the airplanes.

## **Advantages of High Altitude UAVs**

**Larger footprint than most manned aircraft**

**Fly above most weather conditions**

**Fly above most manned aircraft**

**Closer to Earth than satellites**

**Loiter over one location for long periods**

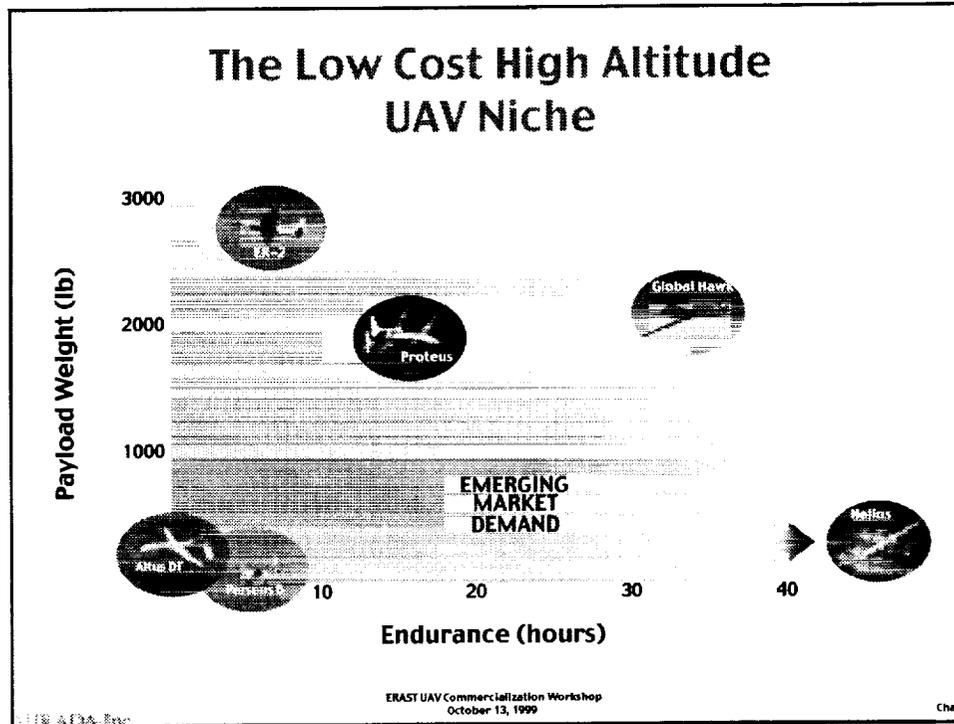
**Direct access to the lower stratosphere**

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Chart

Spending on high-altitude UAVs is going to continue to grow because they have some unique attributes. The most important one is in the footprint. That is, when you're looking down from the UAV at the ground, you cover a lot of area. If you're at an altitude of the order of 60,000 feet, you'll cover about four times as much area as you would with a piloted airplane, say at about 30,000 feet. That's a big, big advantage. There are other attributes that really help as well. You can fly above most of the weather. If you're at 60,000 feet you're not subject to weather, except when you take off and descend. You also are flying above most of the piloted airplanes, which makes your air traffic control problem easier, again, except during take off and landing. UAVs are also closer to Earth than satellites. For missions where you want to take high-resolution imagery or where you're going to do telecommunications, that proximity to the ground has a tremendous benefit.

There are some other advantages. In the other workshop, the scientists get very excited that you can actually take measurements within the stratosphere. That provides some unique capabilities in what we hope is a low-cost platform.



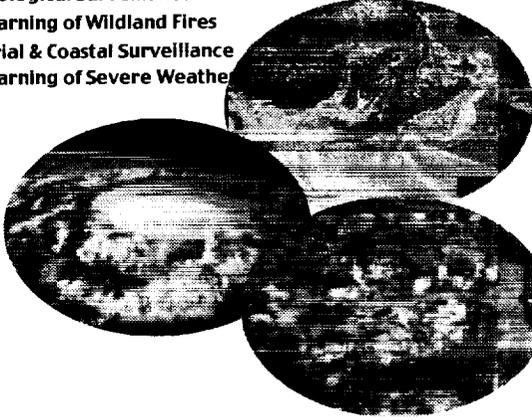
Where we see the market emerging is an interesting void. In the lower left-hand corner are two of the vehicles that we saw in the hangar today—it's Perseus B and Altus DT. They are first-generation vehicles. They're inexpensive. From an operational standpoint for commercial service they really don't have as much performance as what is needed. You have to carry more payload, and you have to stay up in the air considerably longer. There are airplanes that offer that performance. The ER-2, which is a piloted airplane, certainly carries more weight than is necessary. However, you can't really stay in the air very long, and it's an expensive platform. There's a military airplane development—the Global Hawk. That airplane is going to take part of the market. We don't call that a low-cost UAV. Once it's in production and once the Air Force has bought some, the marginal cost of buying additional Global Hawk airplanes is going to be very attractive for some non-military users.

Finally, here is Helios, and Helios is really off the chart. This chart goes to about 40 hours endurance. That provides a breakthrough in capability. If you have the many-day airplane up there, there are things you can do that we really haven't even thought about. It's revolutionary in capability. When you put a business assessment together, it's hard to put your arms around exactly what the market is pulling.

## Potential Applications

**Monitoring & Early Warning**

- Meteorological Surveillance
- Early Warning of Wildland Fires
- Territorial & Coastal Surveillance
- Early Warning of Severe Weather



**Environmental Sciences**

- Atmospheric Research
- Oceanographic Research
- Mapping & Environmental Monitoring
- Test Support

**Telecommunications**

- Service Niches
- Disaster Recovery

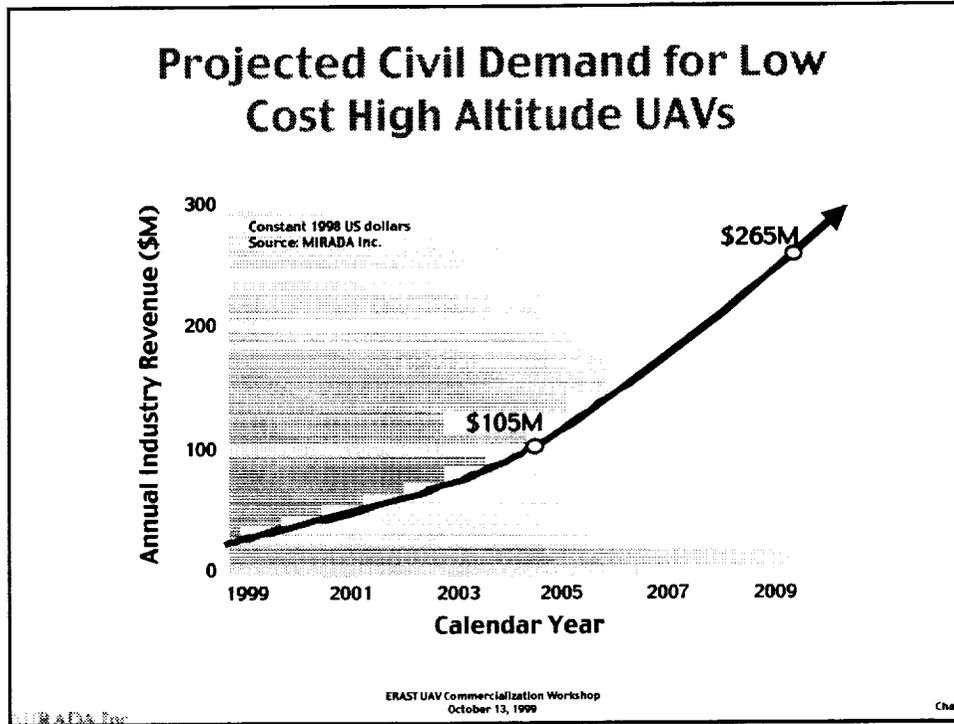
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What we do know is there's a bunch of users here. They want to carry five, six, seven hundred pounds of payload. They want to have an airplane that stays in the air for whatever their requirements are, give or take. And that's where the market's coming.

We see the applications that marry up to that demand coming in three areas. The first and the largest from the ability to generate revenue for industry is in monitoring and early warning—that is, you fly an airplane, it observes something, and perhaps it tells you something is about to happen like a wildfire is beginning or a hurricane is approaching. That is where we think there is commercial value, and it is difficult to provide comparable service with any other platform. It gives you some real economic advantages.

The second market is environmental sciences. This is what again is going on primarily in the other workshop. This is doing atmospheric, oceanographic research, mapping some environmental assessments, and the like. However, you have to recognize from a business standpoint that all the customers in that market are government agencies. Because of that, it limits the profitability. There are revenues to be made there, but there's an argument that can be made that says it's not a very profitable market in the long run.

And finally, there's telecommunications. We know there are two telecom applications for high-altitude UAVs right now. The first is in service niches. Although there's a lot of satellite operations now being fielded, there are gaps. There are geographic gaps, and there are gaps in time where UAVs could provide some service. There's also in disaster recovery areas where you have a system where the satellite ground infrastructure is no longer in place, and you can quickly put an airplane in and provide 1–2 weeks, 1–2 months, or whatever it takes to get your communications connectivity back. Those provide some interesting market opportunities for UAVs.



In the next 5 years the market will be growing at about 23 percent a year. So it would be about a \$100 million market by the end of 2004. The market would continue to grow at an average rate of about 20 percent a year. By the end of 2009 you would be looking at \$265 million going into the UAV industry to support these applications. Now, that looks like a lot relative to the \$28 million that's being spent today. However, if you're trying to get investments to develop a new UAV, it's a pretty small number, and that's part of the problem. This is not a large industry. This is not like the global telecommunications industry where you have global telecommunications at the end of that chart, a \$1 trillion industry. So the scale of this business is small enough to be profitable, but it is not a huge industry by a lot of other high-technology standards.

## **Speculative High Payoff Applications**

### **Multi-Function Support of Disaster Response and Recovery Operations**

- **Provide telecommunication services and imagery from a single airborne platform**
- **Potential to improve disaster response at modest cost**

### **Telecommunications for Mass Markets**

- **Directly competes with major satellite systems (Teledesic, Spaceway, Astrolink, etc.)**
- **Potential to significantly increase demand for high altitude UAVs**

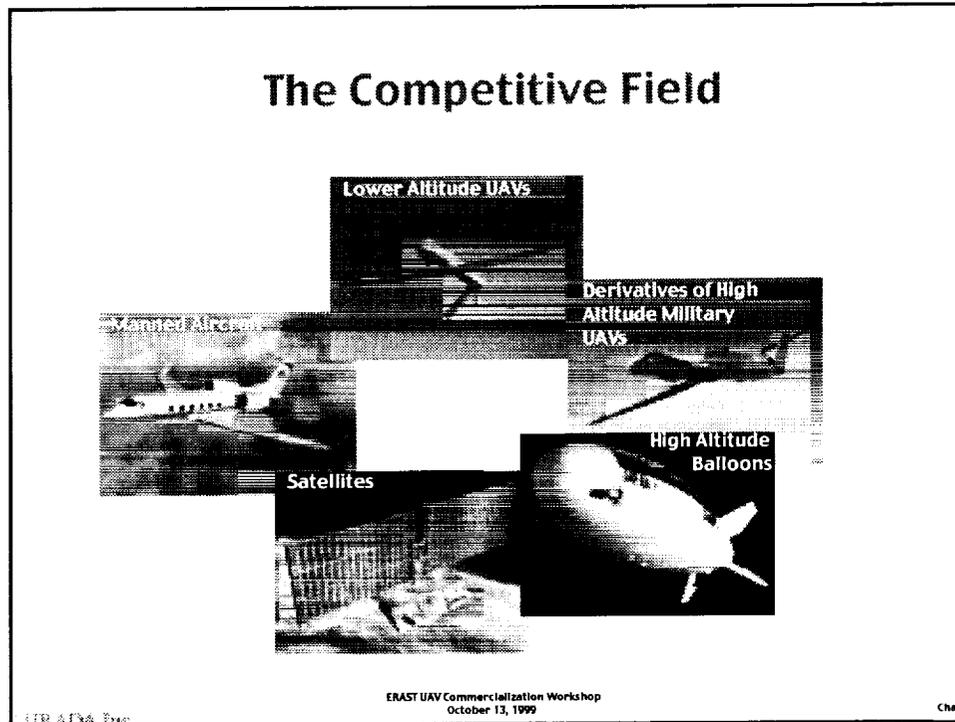
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There are applications that could make a significant difference and make the growth steeper. The first is what we call multifunction support disaster response and recovery. The immediate need is to provide communications connectivity in the part of the disaster. You could actually sell a service to do that. Once you have a UAV there, you can do the things that we saw in the previous session. We now have a platform there, and you could use it to capture imagery. By providing all that in a single platform provides a new capability that, frankly, they've never had before. That capability could increase the use and demand for UAVs. It will not increase the demand significantly in the long run, but it would make a substantial near-term increase. For instance, it could make on the order of about a 10-percent increase in the market size the next 5 years, unfortunately because there's a growth demand in disasters. The telecommunications for mass markets is something else. There it doesn't do a lot of near-term improvement to the market, but it could make a substantial difference in the long-term UAV market.

In the next 10 years if you were able to use the UAV, that would now compete against the big satellite systems—Astro Link, Cyber Star—things like that. This could add 50 percent to the market that I just described. It would clearly become the dominant application and would change the entire economic nature of the industry. However, you're also competing against some very large companies that are exceptionally well financed.

You have to separate in your mind what the revenue is to the company actually providing the telecommunication services, which is where the profit is—and the folks selling and flying the airplanes, which will be a subcontractor, and your margins could be squeezed. Although there is an opportunity for a lot of revenue, it's unclear how profitable that would be from the UAV industry standpoint. It could certainly make a big difference in the number of UAVs you're selling.



There's also competition out there, and it comes from five sources. The immediate one is piloted airplanes. Piloted airplanes, for most UAV missions, represent serious economic competition. You heard in the previous sessions a lot of people talking about remote sensing. What you do not see in my list of applications is a lot of words about remote sensing. That's because it is our assessment that most airborne remote sensor demand in the next decade can be more economically filled by piloted airplanes than they can by UAVs. The cost difference is substantially in favor of the piloted aircraft.

There are some applications, though, where UAVs will be particularly useful, such as in dangerous missions. However, those now require high-altitude application. Low-altitude UAVs, not necessarily those that skim the ground but perhaps those that fly at 30 or 40,000 feet—particularly those that have already been bought and paid for by the military and are converted into civil derivatives—may, in fact, provide some competition and squeeze the market a little bit.

There are also civil derivatives of the big, expensive military UAVs like the Global Hawk. Clearly that is going to take a piece of this market. There are customers who will buy a system like that and be able to say they're flying a system that the Air Force flies. There are also groups of companies that are financed and some governments spending money on high-altitude balloon systems. These range in size and technology from some that are relatively near term to some that are far beyond even what you're seeing in the Helios. The Japanese are investing. There are a few venture companies in the United States developing that technology. They are all oriented at the telecommunications market because they're very expensive to develop, and that's the only market that can generate the revenues for them.

Finally, of course, there are satellites. There are a lot of new lower orbit satellites, remote sensing satellites, some of the niche players in telecommunications that are emerging—all those are going to compete with what we're doing in UAVs.

## **Obstacles to Market Growth**

**UAV Reliability**

**Availability of Global  
Satellite  
Communications**

**Regulations**

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Chart

There are also some other obstacles, other than just sheer competition to the market growth. The most important one, in my opinion, is UAV reliability. Forty to sixty percent of the operational cost of using the UAVs you saw today is insurance. It's hull insurance. If you're going to run a business, you have other kinds of insurance. There's third-party liability insurance. There's business disruption insurance. That number is driven solely by UAV reliability. That's what the insurance companies are concerned about. UAVs have to get a lot more reliable before they're going to be commercially viable.

There's also an interesting little paradox. On one hand you would like to compete against global satellite communications. But for some, particularly the scientific missions, those missions require operating UAVs at very long ranges, that is, controlling the UAV and bringing payload data back through satellite communication systems. So it becomes an interesting situation. In one of those market segments you want to compete with the global satellite companies. On the other hand, you actually need them as a supplier to provide a very key service for you to operate. That paradox hasn't really been sorted out. This whole business is moving very rapidly. But it's a significant problem. The scientists are real hogs for bandwidth. They don't want bandwidth such as some of the new systems—the radium ICO for example, which is voice cell phone class bandwidth. They want megabits through space. That could be done. It's very expensive. It's going to come down in cost. On the other hand, they're going to need that and they're going to want it—particularly the kind of images and the kind of data you were just seeing.

Finally, you heard a lot of discussions earlier today about the regulatory environment. These are aircraft. They not only have to meet regulatory requirements in the United States; they have to meet regulatory requirements around the world. It's not just air traffic requirements, it's also radio communications regulations. You're going to have to operate in certain frequencies. That becomes a real problem in foreign countries.

## The Opportunity for Commercialization

**A commercial market for low cost high altitude UAVs is emerging**

**There are some obstacles to attracting adequate private investment**

- UAV reliability
- Availability of global satellite communications
- Regulations

**NASA's ERAST program is working to address these obstacles**

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Chart

To close, we think there's a commercial market. It's growing. It's attractive to make investments in some areas. There are obstacles that have to be overcome. Competition is going to be there. But UAV reliability and trying to bring down the cost and availability of global satellite communications are also important. Working the regulatory situation is important. That's what ERAST is trying to do—to build confidence, and work with the other agencies involved to go and try to create an environment that can foster commercialization.

Question: This is Eric Brachhausen. What do you consider to be a low-cost, high-altitude UAV?

Basil Papadales: Five million dollars a copy. That number moves around too, depending on what the expenses of UAVs are. The easy way to think of it is half the cost of the Global Hawk, because that's exactly the way customers think of it. A Global Hawk, once it's in production, without payloads, will cost somewhere between \$10 to 15 million if everything goes right.

Question: So you feel the Global Hawk platform itself will be available in a commercial environment in years to follow?

Basil Papadales: If there is demand for it. One of the things I didn't talk about is how you actually offer UAVs to the marketplace. We were saying that there are alternate ways of doing it, rather than buying a UAV flight service and things like that may be necessary, particularly an expensive platform like Global Hawk. Some people are going to want that class of service.

Question: This is Nick Colella. It's very important to make the distinction that the Global Hawk is a single-engine platform. And to offer its services in the U.S. on a commercial basis, or trying to get FAA certification to do so, they may run into some issues like single-engine operation.

Basil Papadales: There's another airplane, Proteus, which has about the same performance with two engines. But the single versus two-engine issue to me is a secondary issue. I realize some people think it's big. But the big issue is that there's an installed base at the Air Force utilization. So you can see a Global

Hawk airplane looking like an ER-2. An ER-2—NASA would never have an ER-2 if it were an installed base. The U-2 is already out there. That analogy is going to hold. Whether it's 10 percent of the market or 40 percent of the market remains to be seen.

Question: I was just questioning whether Northrop will be able to sell the Global Hawk platform in a commercial environment or whether it be restricted.

Basil Papadales: That's their business problem with the Air Force. I would think that would be beneficial to the Air Force.

Question: You talked about the regulatory process. Can you characterize what the current state of affairs is with regard to FAA and their view of UAVs?

Dale Tietz: I'd like to route that over to Glen Witt.

Glen Witt: Next week at Las Cruces, New Mexico, an organization that we put together called the Technical Analysis and Applications Center is putting on a symposium. The following day on Tuesday we're going to be addressing specifically those issues such as aircraft certification, operating qualifications, and procedures for operating in national airspace. The goal of the Technical Applications Center is to engage with the FAA to come up with procedures and all that—I have with me two gentlemen. Gary Nakagawa is FAA—30 years of aircraft certification experience. Ken Erdman is in flight standards—35 years with the FAA in flight standards experience. I have 34 years of air traffic controller experience. Our team has experience in the disciplines we're talking about. Now, we're not saying we know all the answers. But I think we know how to ask the questions and go through the mechanics. So, I will be able to speak to a lot more of those issues in detail next week and off line after we get through with the ERAST Program. I'll put up some World Wide Web sites here.

Question: Your briefing and the results or recommendations or conclusions seemed a little bit askew. I wondered perhaps what the underlying reasons for that were. You painted a bleak picture. Two hundred sixty eight million-dollar market, kind of a niche market, in many regards small, civil, science, etc. Then you showed all the competition. Yet in your conclusions or recommendations chart you said, there is a market—there is an opportunity here. Is it a way of looking at it?

Basil Papadales: You have to look at it this way. It's an opportunity for small companies. It's a small business from the Hughes Company point of view. Most of these alliance companies are really small companies. I mean we're talking about if this market comes up they'll triple, quadruple their revenues. I mean it's a big opportunity for a little company. It's not a big opportunity for Northrop Grumman or Boeing, or some large company. Now maybe it will be in 10 years when that market grows. But that's part of the scale—people need to understand the scale of the business. That's why supporting little companies is important, because it's just too small a business to attract big companies.

Question: But you mentioned a breakthrough off the chart here with the AeroVironment aircraft.

Basil Papadales: I think everyone agrees. That is truly a breakthrough that people can speculate upon. That is a remarkable breakthrough in aeronautical capability that would be like asking me in 1902—now what does it mean that Orville and Wilbur really fly, you know. I mean that's truly a big deal. And it's hard for people to say—Well, I'm going to buy something in 2007 based on that.

Dale Tietz: Dr. Nick Colella is with us today to provide his thoughts on Angel Technology Corporation, a company founded to provide broadband telecommunications to metropolitan areas using a piloted aircraft called the Proteus. Future generations of this aircraft may become robotic to take advantage of high altitudes, better performance, wider footprints and better economics. Nick became involved with robotic airplanes in 1991 while he was working at the Lawrence Livermore National Laboratory on projects for

missile defense. Nick then left the Laboratory and went into the private sector where he is today. Nick also was the founder of a company called nChip, a multi-chip module electronics packaging company, and he is also a founder of the National Robotics Engineering Consortium at Carnegie Mellon. Nick has a Ph.D. that he got through Carnegie Mellon as well. And so today he'd like to give us an update on his telecom thoughts, right?

**Angel Technologies Corporation**

**The Rise of Stratospheric Communications  
& The Fall of Satellite Networks**

**NASA ERAST "Exclusive Preview Event"**  
NASA Dryden Flight Research Center  
October 13, 1999

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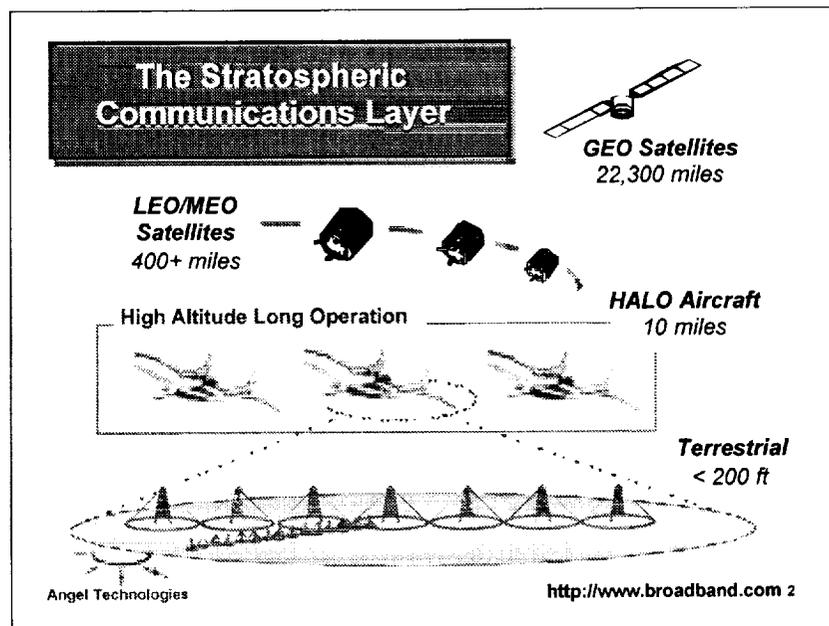
<http://www.broadband.com>

Dr. Nick Colella: Thank you. Yes. It's really interesting that often when I talk to the investment community I get the question that "If stratospheric communications," which I'm going to talk about today, "is such a good idea, why wasn't it done 10 years ago?" And, in fact, there were proposals by Westinghouse Corporation in the early '50's precisely about wireless stratospheric communications. A lot of patents were filed. What makes it practical today is the technology base—and I'm going to go through a couple of points on that—but also there is the potential market pull, and not only the market pull domestically but also internationally.

Clearly, there are now methods of making small, highly capable airframes. Manufacturing methods have matured quite a lot, mainly due to funding through the Defense Department, but also due to a very robust business jet industry in the U.S. and abroad. At the same time, wireless broadband access technologies suddenly got released at the end of the Cold War, mainly because a lot of engineers got pink slips. Suddenly a lot of technology that was very high value added to certain defense contracts walked out the doors with the individuals who then teamed up with entrepreneurs, or became entrepreneurs themselves, thus moving wireless millimetric wave technologies out into the marketplace. Now we're seeing companies grow up. Concurrent to that was the liberalization, in Washington, of spectrum through the Telecom Reform Act, which led to people providing new access modes. While you had that, you had the data communications industry being fueled by Moore's Law, a factor of 2 performance increase every 18 months. I recall the people who founded Four Systems, which is an asynchronous transfer mode (ATM) switch manufacturer in Pittsburgh, Pennsylvania. The kind of switch technologies they looked at as grad students and one as a professor at CMU were pathetic, when compared to what they're marketing today. Talk about 40 gigabits per second packet switches—orders of magnitude higher than what they prototyped just less than a decade ago in the university.

You're seeing the technologies for the terrestrial markets in how you close the air link, how you modulate the signals, how you work computations and communications all the way up to the application layer, basically being fueled by Moore's Law, except, perhaps, for the millimetric wave components that are evolving more slowly. The great hope there is that Silicon Germanium will suddenly increase that rate of evolution of those components, perhaps under 10 gigahertz initially. Silicon Germanium—there's some speculations—might be able to go up to 30 gigahertz, 50 gigahertz. With manufacturing methods closer to silicon (than GaAs), there can be a world-manufacturing base for Silicon Germanium—and suddenly it's rock and roll for millimetric wave communications. So there's this great convergence here.

And last of all, everybody wants a website, you know. There's this commercial in California about "my-shoe-laces-are-untied.com" or "I-have-a-straw-stuck-in-my-ear.com." But on the serious side, many small businesses recognize that to survive they've got to be able to take orders in a very facile way, they've got to be more responsive. In essence, they've got to start moving closer to the "market of one." When you want to order something—they have your order and it's clean, it's distinct, and it goes to you. Instead of just bulk production hoping to get your buy, it's now targeted directly.



If you do deploy a stratospheric layer—and ARTIS technology makes it possible and the market's ready to accept it, however, this potentially is a very disruptive technology. There are big cats out there that aren't going to like the idea of stratospheric communications—which brings me to the title of my talk "The Rise of Stratospheric Communications and the Fall of Satellite Networks." What I mean by the stratosphere or by the stratospheric communications layer is operating above the commercial airline airspace. That's the stratosphere. Now that's not a correct technical definition, as you know. An atmospheric chemist will get very upset with me. It's the layer above where we do commercial airline operations, so that we can loiter and operate above cities.

## Benefits of Stratospheric Comm Networks

- ◆ Can match the telecommunications density to the end user population of each major city
- ◆ Have short round-trip signal delays
- ◆ Allow real-time, multimedia dialogue
- ◆ Expand with regional e-commerce
- ◆ Are attractive for international "green field" deployments
- ◆ Easily integrated with terrestrial networks
- ◆ Can be grown into a global business
  
- ◆ *"If it can be done, it will be done," Andy Grove.*

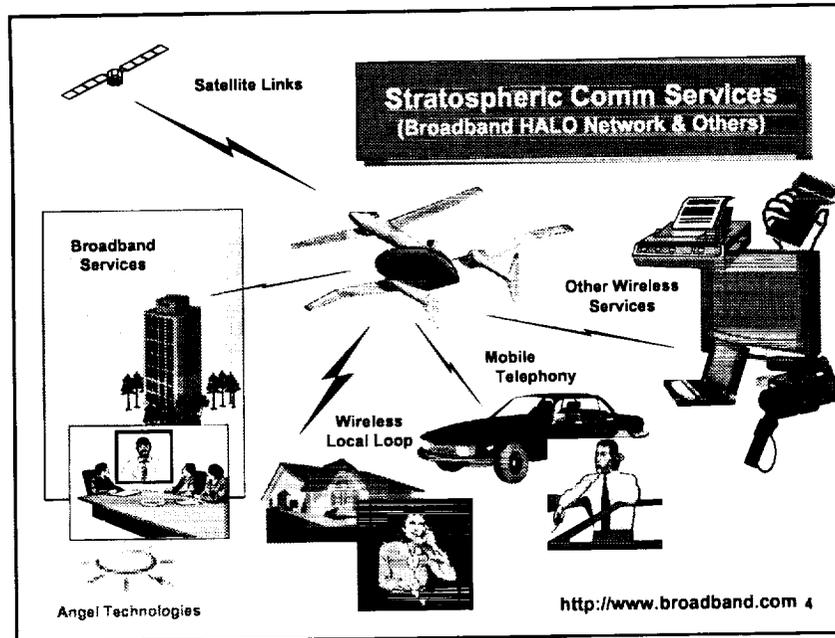


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Now the benefit of stratospheric com networks, in general, is that because you are above the addressable market and with advances in antenna technologies, one can match the offered telecommunications densities to the addressable market. If you're business based—and you're trying to offer business to the small office, to small businesses, and connections to them—if the distribution is very heterogeneous, as it is in most cities, you can still match that morphology and be efficient with your use of bandwidth. What's attractive from a data communications network standpoint is that you have short round trip delays in your signal propagation. On the scale—on the air interface of about 100 microseconds round trip to multiple hundreds of microseconds, but not milliseconds or multiple milliseconds.

Consequently, because you can achieve high-data densities with short round trip delays, that allows you to use communications protocols that are appropriate for multimedia. Suddenly you have this single node—one that provides a single footprint that allows real-time multimedia dialogue. Some people refer to it as virtual telepresence, immersive telepresence, etc. By now being responsive and immersive, that will expand regional commerce.



In the U.S. there are many opportunities for deploying broadband access. There are twisted wire pairs. Certainly in the upper tier cities the twisted wiring is relatively mature. It's been upgraded. The competitive environment is right to offer access to twisted wire. Cable modem is going to be very competitive for the home market. Fiber to the tall buildings, and then wireless access. There are still places in the United States, though, where an overlay—a wireless overlay can be very effective. That's especially true when you want to move signals on a length scale of tens of miles instead of individual miles, and you want to do so to connect closed user groups—small businesses—to the headquarters, telecommuters, business offices. You want to do store and forward of large files, and you don't want to pay the connection rate that's due all month long when you're just doing a file transfer for minutes each day. Particularly attractive are stratospheric networks for international green field deployments, wherein you can't do an upgrade of the existing twisted wire infrastructure.

It's interesting to note that in most of Japan when they did twisted wires they took two wire pairs together, and rather than putting in a metal sheath which would contribute some isolation and eliminate some crosstalk, they used paper to wrap the twisted wire. So the crosstalk problem in Japan is much worse than in the U.S. When they look at ADSL deployments in Japan, it's going to be more problematic than here. And that's a very developed country. So in that sense it's almost a green field.

A stratospheric network can be easily integrated with terrestrial networks, which I'll show in my talk, and can truly be grown into a global business, one city at a time. You learn by addressing each market. You generate your revenues. You study each city as if it's an individual market. You don't try to anticipate the whole world. And to quote Andy Grove, "If it can be done, it will be done." I think it will happen.

## Benefits of Stratospheric Broadband

- ◆ High Density Coverage of a Major City and Neighboring Towns & Communities From One Airborne Network Hub
- ◆ Immediate Service to All Potential End Users on the First Day of Deployment to that City
- ◆ Ubiquitous Access with High Look Angle
- ◆ Timely Upgrades In Step with Terrestrial Networks
- ◆ Can Accommodate “De Facto” Standards Arising from Global Competitive Forces



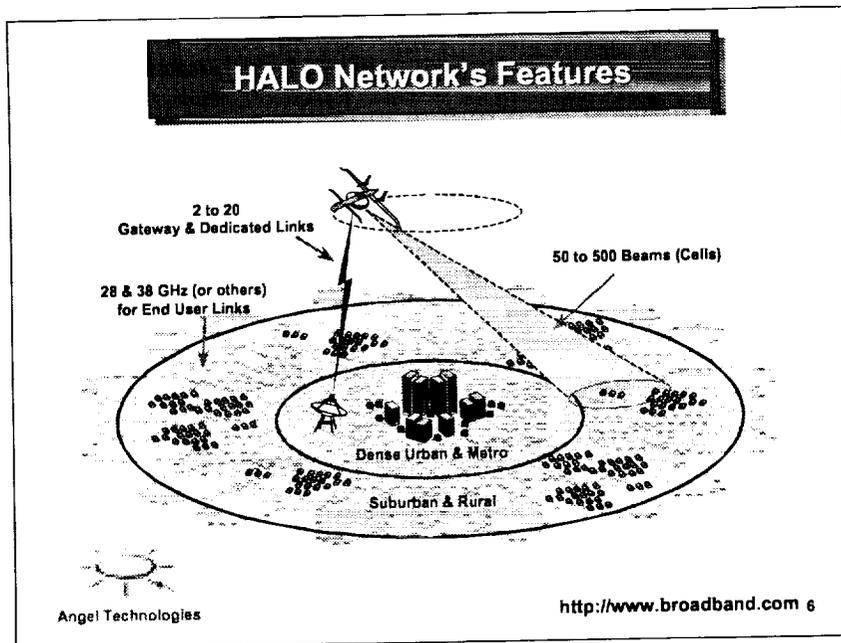
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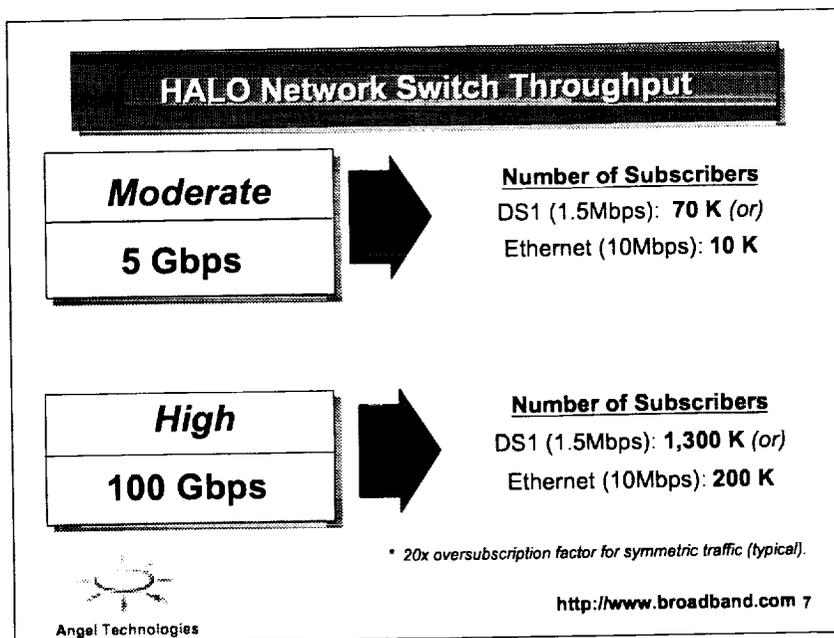
There are a variety of wireless opportunities for stratospheric platforms. I will focus specifically on broadband today. We have, indeed, looked at wireless local loop, which is very attractive in the international context, next generation mobile narrowband services, data, telephony, and other wireless services and devices that would happen in the next generation services. Those are all potential markets. Broadband access—there’s a bandwidth frustration. If, some day, bandwidth becomes a commodity, you can then bundle this type of access with the right types of information services, and suddenly customers can do things that are potent for e-commerce.

The benefit of stratospheric broadband is that a single stratospheric node can cover a major city and do so at most cities in the world. Los Angeles is an exception. New York’s an exception. They’re unique morphologies. But most cities in the world, plus their surrounding towns and communities can be covered. That’s a great recipe for addressing telecommuters and for connecting small businesses to the downtown, etc. It is immediate service to all potential end users on a first day deployment to that city. So it fundamentally changes your marketing strategy, how you roll out. In the case of local multipoint distribution service (LMDS), you have to look at one business park at a time and convince them that you’re going to be in the next business park down the street, and some day “you will all (be able to) get together.” Where here there’s another way of marketing and there perhaps are some real economies and efficiencies in being able to do a “one-city” rollout. It offers ubiquitous access with a high-look angle. Therefore, just about every single rooftop can be a potential customer. The cost per rooftop passed is quite low with the stratospheric node.

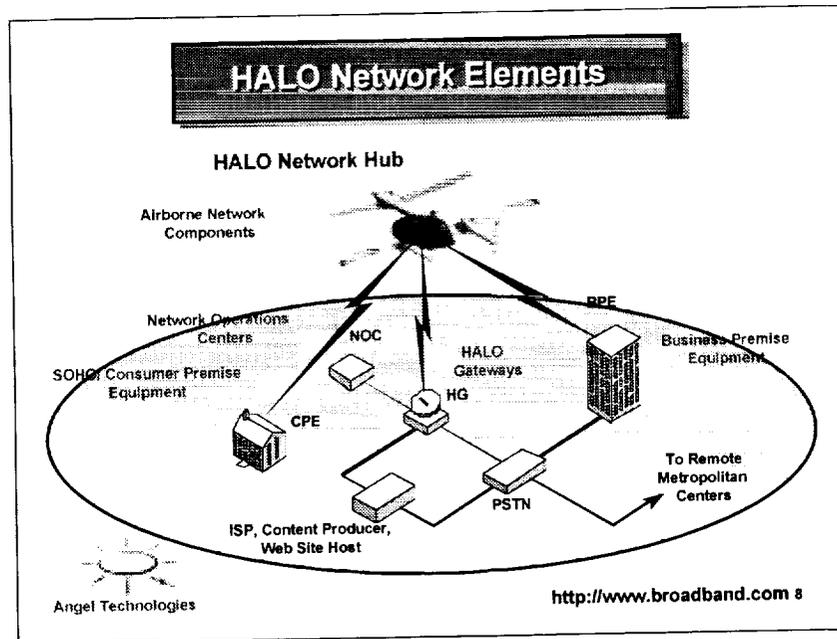
The timely upgrades—and this is very important relative to a space network—is that the real advances in data communications are going to happen through terrestrial data communications networks. There’s a tremendous amount of money behind terrestrial data communications. Stratospheric platforms can accept that technology. By having fluidic cooling, by having a partial atmosphere, by having ample power and volume, etc., you can integrate that technology; you can change it, evolve it, and stay with the technological trends that are fueling terrestrial networks. That leads to the next point which is—by being able to accept the technologies from terrestrial networks, one can respond to and accommodate the “de facto” emerging standards before they’re accepted—the standards that you bet are going to win. If that standard doesn’t win for some aspects of your communications network, then you can respond and move with the industry.



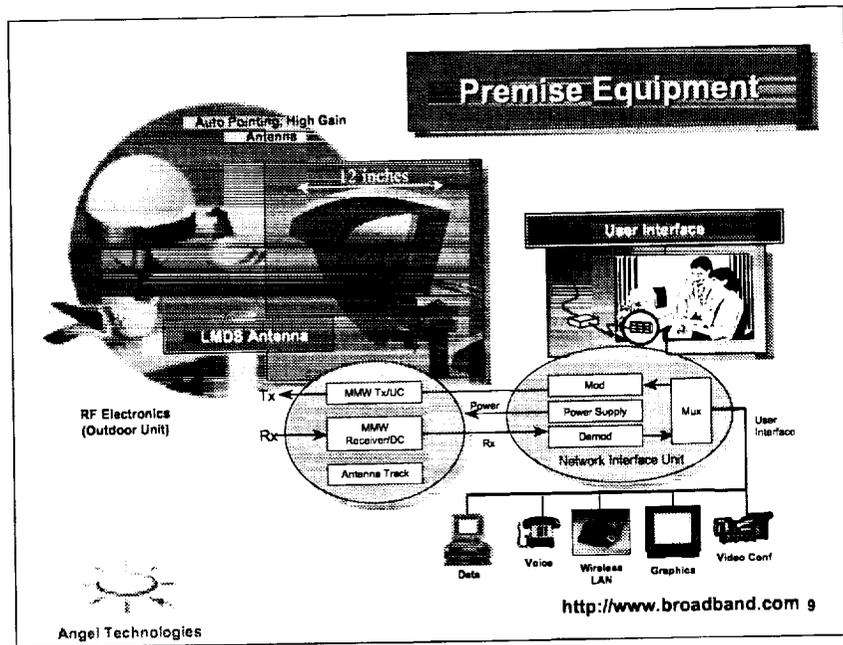
In the case of a broadband network and feasibility of a class of payload that we've talked about, I will give orders of magnitude to orient people. That, in terms of dedicated beams, could then be to a high data traffic business or to a gateway, two to twenty dedicated links—that really isn't a limit, but that fits nicely in the envelope. Fifty to 500 beams can be combined in cellular patterns to give shared access per beam. You could do a packet switch network. The frequencies where there's nice bandwidth to give the types of data throughputs I'm going to talk about are available at 28 gigahertz and 38 gigahertz. There's an evolving and growing technology base to support 28 and 38 gigahertz.



If, for example, you develop a network that has a switch throughput on a scale of 5 gigabits per second, with a typical bandwidth over subscription factor of 20X, one can support a subscriber base of about 70,000 people, if their statistical average data rate is about 1.5 megabits per second. And that includes users that are off net, on net, etc. This is a subscription base for that type of throughput. If you can then go to 100 gigabits per second for the communications node servicing that one city market, one can then serve on a scale of a million subscribers. I show a factor—roughly a factor of 6 difference between if they're going at one megabit per—one and a half to ten megabits per second.



The types of elements one would have in a stand-alone network would be small premise equipment or user terminals on the rooftop with a clear line of sight to the stratospheric node. In the case of a dedicated link where, for example, this might be a web hosting facility like Concentric Networks where they provide value added web hosting for small businesses, they might have a dedicated beam that allows them to then reach their customers through this airborne node.



The other network element is that for traffic that needs to get out of the network, it could either go through one of these links that's connected to the public switched telephone network (PSTN) or through a gateway to the PSTN. The gateway also offers a portal for individuals who want to move content to the entire subscriber base. Here's a real revenue opportunity for this type of network by being able to provide a multicast opportunity.

To provide service to multiple cities, the network operation center (NOC) responsibility could be shared over multiple cities. If there's only one city that's done, then you need to provide some kind of network support functions and billing structures.

Working closely with Raytheon Corporation, the group that came from Texas Instruments (TI), before we leaped into this project we said—can we work with LMDS equipment? Can we take the equipment that's being developed for LMDS and replace the base station on a building with a base station at about 50,000 feet altitude? The answer came back "yes." It took careful thought and engineering in what's required. What we found is that you could use the LMDS rooftop unit, and you could use the indoor units as proposed and evolving with a standards body. What will be required in the case of a high-gain antenna if the stratospheric platform is moving would be then some type of pointing capability. There are a variety of low-cost options that have been looked at for how to do that pointing capability if the stratospheric node moves.

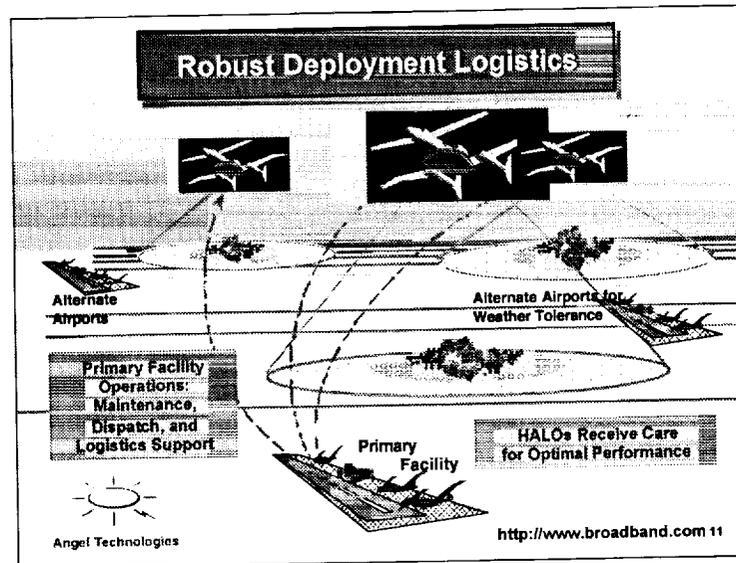
## HALO/Proteus Airplane Attributes

- ◆ Twin-turbofan propulsion for routine operations above 51Kft
- ◆ Two-pilot certification (FAA Part 23), one active pilot with autopilot operation on station. (Optionally piloted mode in the future.)
- ◆ 6,000 ft altitude "shirt sleeve" cockpit while on station
- ◆ Small business jet airport operations: 95 ft span; GTOW of 12,500 lb; Fuel Weight of 5,500 lb
- ◆ 20 KVA for airborne HALO Network components, about 2 to 10 times higher than satellites.
- ◆ 1,800 lbs & 18 ft diameter payload pod beneath the fuselage
- ◆ Large fuselage volume for payload components
- ◆ Modular fuselage barrel for swapping payloads



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In the case of High Altitude Long Operation (HALO)/Proteus, I think you've heard all these specs. The important thing is that there's an optionally piloted mode in the future, if the ERAST Program is successful in its objectives. If Scaled Composites happens to be one of the beneficiaries of that success story, then we'll certainly see a nice transition from piloted operation consistent with the FAA Part 23 to optionally piloted. As Burt Rutan mentioned, it's a shirtsleeve cockpit. It's actually a sealed capsule environment. The airplane was designed to operate from small, local, county airports. We did a survey of the United States, and we found more than 3,000 airports in the United States can support our operations. Because there are so many airports where we could fly our small business jet from, what we do to achieve robust deployment logistics is to operate from a primary facility, but within a 500-mile diameter we have a number of secondary airports established. In the event that the primary facility is weathered-in or we can't land and relieve the node, then we operate out of a secondary airport. We use modern meteorological tracking capabilities to know when we rotate the assets between primary and alternate airports to stay robust—much like—and done with great discipline and success by the AeroVironment team.



With the Raytheon team, Angel performed a wireless broadband demonstration with standard equipment made for terrestrial communications applications. The airplane used was actually a Cessna. What we did is we replicated the slant ranges that we would have in our network, and we also did the look angles relative to local horizon. Through that we did multiple videoconferences. We aggregated voice traffic. We did IP over that link, etc.

**HALO Network Milestones (Private Financing)**

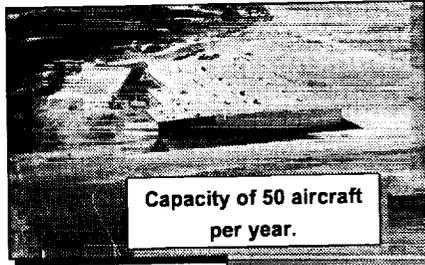
- ◆ Oct 97: Scaled Technology Works Factory Completed
- ◆ Jul 98: HALO/Proteus First Flight over Mojave, California
- ◆ Aug 98: 52Mbps Demo over Dallas by Angel & Raytheon
- ◆ Sep 98: HALO/Proteus Inaugural Flight
- ◆ Feb 99: HALO/Proteus Flight Above 50Kft
- ◆ Jun 99: Paris Air Show International Debut
- ◆ Sep 99: Comm Pod Aero Flight Check
- ◆ Oct 99: ERAST "Exclusive Preview" of the HALO/Proteus

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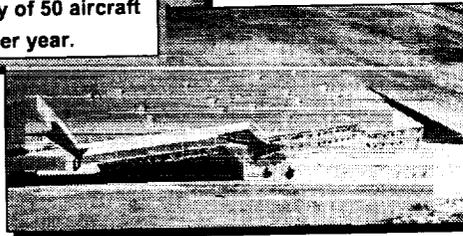
We debuted the Proteus in June of 1999 at the Paris Air Show. You saw the telecom pod; the aeroflight check was done in September of '99. Here we are today, and you saw the com pod today. Those of you who love to go to Colorado—if you're in Montrose, there's the Scaled Tech Works factory. It's capable of producing 50 aircraft per year of this class. A decision to capitalize that facility was based upon the HALO/Proteus, as well as manufacturing carbon composite components for other aircraft—certified aircraft. This is probably worth showing, because you saw the real article today.

## HALO Aircraft Production



Scaled Technology Works  
Montrose, CO

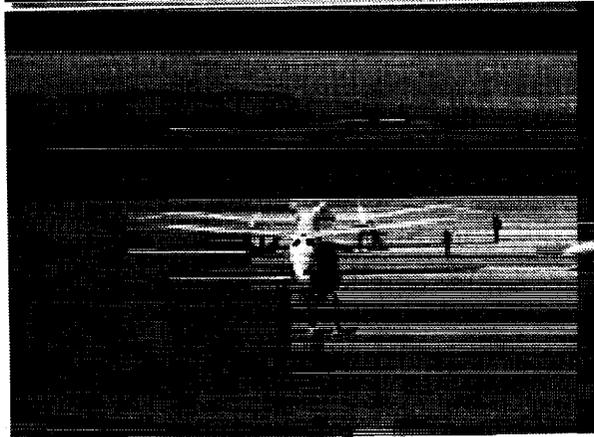
Capacity of 50 aircraft  
per year.



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## First Flight, July 1998



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### **Commercial Aspects of Stratospheric Broadband Services**

- ◆ Seamless ubiquitous multimedia services
- ◆ Adaptation to end user environments
- ◆ Access to the consumer, small office/home office, and content information markets
- ◆ Rapid deployment of complete network solutions to cities of opportunity
- ◆ Total coverage of the city and its surrounding communities on the first day of service
- ◆ Bandwidth on demand for efficient use of available spectrum



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The commercial aspects of stratospheric broadband services are that if you engineer a network properly and you respect what people are doing with terrestrial networks, you can make such a connection seamless to the end user. You have to do that. Furthermore, you want to anticipate the end user environment and adapt to it and anticipate how that end user environment is going to change over time. If you are successful at that, then what you'll end up with is access to the consumer, small office, home office, and emerging information markets. We think once you have that template you can then deploy to cities of opportunity—not quite in a cookie cutter fashion, because you have to optimize for each market to understand it, but you could roll it out in an evolutionary manner. You could be very efficient with the available spectrum because you can offer bandwidth on demand through a simple star topology network with a single hub in the air.

### **Stratospheric Platforms: A Better Broadband Alternative**

- ◆ The shorter range from the stratospheric node to the end user (10 to 35 miles), allows the use of low-cost, low-power premise equipment.
- ◆ The premise equipment requires a single beam with slow angular tracking (perhaps zero rates), instead of two beams for LEO constellations.
- ◆ Data densities can be nearly one thousand times higher, e.g., 2-20 Mbps/sq-km.
- ◆ Round trip time delays will be acceptable to interactive broadband services, e.g., 100 microsec to 350 microsec



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Compared to Low Earth Orbit (LEO) satellites, the premise equipment can be less expensive and lower power, and also only requires one tracking beam or one stationary beam, but not two. LEO satellites require two because there's one satellite descending while the other's ascending ... you've got to maintain the link. The data densities can be nearly 1,000 times higher—2 to 20 megabits per second per square kilometer—for a stratospheric node. This is for the shared access. Clearly for dedicated beams one can really chug along to whatever available bandwidth can be offered. Round trip delays are short and appropriate for multimedia and interactive e-commerce.

**Stratospheric Broadband Can Serve High Growth Markets**

- ◆ **Frequencies usage can be decided by a local PTT, or spectrum holder, to extract value from a licensed asset.**
- ◆ **In the U.S., stratospheric networks could access frequency bands licensed to a terrestrial service provider through a business agreement.**
- ◆ **Stratospheric broadband network can serve hundreds-of-thousands of broadband subscribers within a metropolitan area distance scale.**
- ◆ **Data connections to destinations outside a metropolitan service area can be made through terrestrial trunklines.**

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It appears that frequency usage can be determined in an international context by the local PTT and not require work with and coordinating with the ITU, to extract value from a licensed asset. In the U.S., stratospheric networks could access frequency bands licensed to a terrestrial service provider through a business agreement for them to get additional value out of their spectrum. Hundreds of thousands of subscribers can be served by a node over the city, subscribers within a metropolitan distance scale. So it truly is a potent opportunity for e-commerce. Data connections to destinations outside can be interfaced with terrestrial networks and trunk lines.

## Stratospheric Versus Big LEO

- ◆ Uniquely tailored "hub" in a simple star network
- ◆ Easy to diagnose, maintain, and upgrade
- ◆ Readily serviced for optimal performance
- ◆ Commercial technology & open standards
- ◆ Efficient spectrum usage focused on each city
- ◆ Evolving business model with city-by-city learning
- ◆ Many clones in a complex mesh network
- ◆ Impossible to repair once on orbit
- ◆ Steadily degrading asset diverging from its market
- ◆ Special, integrated, proprietary "spaceware"
- ◆ Global spectrum allocation blurring regional needs
- ◆ High risk, long-term business gamble



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Now comes my satellite big LEO bashing. There's a uniquely tailored hub in a simple star network versus many clones in a complex mesh network. That leads to a variety of things. First, the total system topology and complexity are radically different. They're [stratospheric] easy to diagnose, maintain and upgrade—yet [satellites are] impossible to repair once on orbit. [Stratospheric] Readily service for optimal performance, [satellites] steadily degrading asset diverging from its market. You predict a market. You go out there and you launch Iridium, and you find out that nobody wants to buy your hand sets, or you can't ship them, or you've got real problems. That's a serious matter. It's really terrifying the financial markets—look what has happened with Iridium and ICO.

## Important Policy Questions

- ◆ Is the stratosphere better than space for providing "bit clouds" to the populations in major cities of our world?
- ◆ Can a stratospheric platform (SP) more efficiently use spectrum than a satellite for serving needs of people and business?
- ◆ Can SP networks better evolve to meet the growing needs of regional and global e-commerce?



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[Stratospheric] Commercial technology and open standards can be accepted and grown with, versus [satellites] specially integrated proprietary spaceware. Suddenly here's a play that might be commercial. [Stratospheric] Efficient spectrum usage focused on each city versus [satellites] global. If you have the capital and the means to influence the work, then it's no problem. If you're a small company—small satellite companies crash and burn when they try to acquire global spectrum rights. It's very hard to build up that kind of consensus and get a position out of the ITU.

[Stratospheric] Evolving business model with city-by-city learning versus a high-risk long-term business gamble. There are important policy questions, I think. That's what I want to leave with this crowd. My understanding is that this is a workshop. A workshop is to influence policy also. Again, looking at Andy Grove, "If it can be done, it will be done." The question is—"Is it worth doing?" That's the next one. If, indeed it is, by answering questions of this type—is the stratosphere better than space for providing e-commerce bit clouds to population centers? Can a stratospheric platform more efficiently use spectrum than a satellite for serving the needs emerging in e-commerce, or meet the growing needs of regional and global e-commerce better than satellites?

**Important Policy Actions**

- ◆ **Encourage access to spectrum bands practical for commercial services.**
- ◆ **Develop seamless terrestrial/stratospheric standards for broadband wireless services.**
- ◆ **Promote favorable Government environments for testing, rapidly prototyping, and deploying SP networks.**
- ◆ **Foster a world forum and community for SP development.**

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If answers are in the affirmative, then the following policy actions, I believe, are important. That is to have a climate, certainly in the United States and worldwide, that encourages access to spectrum bands practical for commercial services. Now I know there's a 47-gigahertz allocation for stratospheric. That's junk spectrum. Who is making user terminals at 47 gigahertz. Develop seamless terrestrial/stratospheric standards. It's very important that the blurring between terrestrial and stratospheric is done well. That is what's going to be the success story, because the terrestrial buildup is going to happen fast. Promote favorable Government environments for testing, rapidly prototyping, and deploying stratospheric networks. I hope that the ERAST Program thrives. I think this is a nice Government environment. I'd like to see more of it. It would be great to see some rapid prototyping activities, less centered on platforms and more oriented toward payloads and services, to see if these concepts make sense at all.

Last but not least is have a world forum and community. The NASA ERAST might be pivotal in moving forward the discussion at a world level rather than just at a U.S. level. Thank you.

Question: Aren't there real environmental impacts to flying a lot of aircraft in the stratosphere?

Dr. Nick Colella: In the case of the Proteus airplane, at cruise at altitude it burns less than 50 gallons per hour. That's very low fuel consumption. Now for other aircraft. I did an analysis because when I went to Japan, I anticipated that question a number of months ago when I gave a similar talk. If you look at the exhaust of the Narita Airport and then you look at transport mechanisms—diffusion at high atmosphere—and you draw a diameter around Narita Airport because takeoff burns a lot of fuel. So you combine takeoffs and landings and look at how much chemicals are propagating up to the high altitude, it dwarfs this contribution of 50 gallons per hour. The argument that I made is not only is this in the noise of the Narita airspace in terms of pollution, but suddenly a lot of people don't have to commute for hours. So there's the secondary benefit or incidental benefit.

Question: Eric Brachhausen. Out of all the data that have to get transmitted, wouldn't there be some portion of it that isn't sensitive to latency and interactivity—like inventory data?

Dr. Nick Colella: Oh, absolutely. Thank you. I was speaking specifically of interactive real time, multimedia correspondence, and looking at the stratospheric model versus the LEO space model or deeper space model. But, indeed, satellites will have very useful wireless applications. Broadcast satellites—that appears to me to be a very good business model—file transfers, back-hauling, reading sensors, where it's distributed sensors everywhere—like ORCOM. The ORCOM financial model is a very interesting one, being able to read gauges and meters all throughout the world. There are services like that where satellites are going to be very compelling and effective. My orientation here was on the broadband business.

Question: Even in the interactive applications, what do you foresee in the way of getting the information from, say, one of the city-like regions that you described to, across the world? How are the data going to get through?

Dr. Nick Colella: Well, in that case, the latencies are comparable, right. If you go into a terrestrial trunk line and then you employ—and cross the Atlantic with Global Crossing or something—it's the speed of light, whether you're going through that mesh or going up in space and hopping in space. In fact, there are a number of folks who propose hybrid stratospheric satellite architectures as being very clean configurations for providing high teledensities to the city from a stratospheric node, but then being able to connect across the world by a simple couple, you know, jumps on the satellite network. But, in that case, the long haul latencies are comparable in the two systems. But when you're within what—a term I call the “cone of commerce,” then the latencies are very short. We think that a lot of people consume and do their business within 60 miles of where they live. That's what they do. Virtual caching helps, too, for long distance stuff if there are common websites. You could virtually cache at a local web server, and then very much like TCI does with @home.

Question: Nick, Kim Schwartz. When will you or when did you actually fly the Proteus with the payload and prove out the concept?

Dr. Nick Colella: You don't prove out a concept till you go into business. That's what Iridium has taught people. The business concept is not proven out till you make your revenue. But what we did do in the tech trial with Raytheon, we demonstrated a high-speed data link. With this airplane [Proteus], we got the pod on. We're going to do another demo soon, but for proprietary reasons, I won't tell about that. There will be an announcement, and an invitation to industry at the right time. If that's successful, and if we're

successful in the business development, there will be a market trial that will come some time next year. It's finance driven. It's a tough business proposition. You wouldn't believe how many investors I've sat across the table from who, just when you say we're going to do a stratospheric com network, look at you and say—get out of here, what are you doing? What we found is that the investors who were willing to talk to us usually longer than an hour, they would start to say “okay.” We passed technical due diligence a number of times. Once they put their assassins on you, they'll drill you until you fall apart. They say this hangs together, this is making sense. Then it comes back to finance risk, market risk, and business risk. To do a stratospheric network requires someone who can touch the end user, the subscriber, the right kind of access to spectrum, and then the wherewithal to work out a robust operations plan for a new operating paradigm for offering telecommunication services.

Question: Are you looking at initially deploying in the United States?

Dr. Nick Colella: We'll do our initial demos in the U.S. I'd like to see us do our first market trial in the U.S., but it may happen overseas.

Question: Did you do your trial—was it in Dallas?

Dr. Nick Colella: Yes, we did.

Question: And for like the Dallas/Fort Worth area—if you were going to give continuous service there, how many Proteus aircraft would you have to have?

Dr. Nick Colella: For Dallas? One overhead. If it's all by itself and it's an isolated city, you know there are cities around, we anticipate three. We'd probably go into business at first by having one spare somewhere at headquarters.

Question: A minimum of two for continuous service, right?

Dr. Nick Colella: Once you have multiple cities, you could start looking at less than two. But we keep it at two.

Question: But initially—the very first city.

Dr. Nick Colella: You would do three—have three airplanes.

Question: I'm Karen Robbins. We heard the U.S. Program Manager say earlier that the program is committed to helping to look at the issues in commercialization. You're at the forefront of stratospheric telecom. What do you think would be the best areas for ERAST to be focusing resources in to help pave the way?

Dr. Nick Colella: I'm a guest in somebody's house here. I have to really think about that answer, because it's a question of what value. You're saying what value specifically ERAST may be able to offer to my business project. We have a very detailed operating cost model for deploying a stratospheric network—broadband network. Believe it or not, the pilots' salaries are a small fraction of the total cost. When you go to unpowered operations, it's not in there for us. Now when we're in a position where we have to start squeezing the margins, a couple percent here or there—we're going to squeeze margins. But the unpowered operation doesn't do that.

Question: Well, your pilots are going to know that they have to fly 8-hour shifts on station.

Dr. Nick Colella: That's correct. That's what we assume.

Unidentified Speaker: I'd like to make a comment on her question. Being a start-up company as they are, the biggest problem is convincing investors to take a risk. Now if you want to do this technology transfer, the best thing you can do—the Government can do—is to alleviate that risk. How can you do that? You can

do that by making loan guarantees. You get your money back with interest. But you alleviate that risk and the money will pour in from investors like buckets of gold. I'll guarantee that. I'm in that bucket—I know.

Dr. Nick Colella: Actually that's an excellent point. Remember investors—what they look for is they're looking for skin in the game from all parties. So here we are. We've got a platform. They see a financial commitment on the part of the platform manufacturer, plus we have a fixed contract. In the case of the payload, they want to see a financing of the NRE. The investor doesn't want to bear that with risk capital. What they want to bear with risk capital is building out the business to achieve the market objectives. That's really what they want to go after, because that's the risk they're willing to accept—not the technological risk. If there's a mechanism for underwriting the technological risk or offsetting that from the investment community, it sweetens it up.

Unidentified Speaker: I'd say that's the single most important thing you can do to make ERAST go.

Dr. Nick Colella: I don't know if that is or not. I need to think more. I could say that the satellite industry was pretty much subsidized for decades. They built the indigenous technology and capabilities and people and intellectual property base on the basis of public financing. In a case for the defense, it's a very important mission, right?

Question: What are the technological risks that are facing you?

Dr. Nick Colella: The technological risks we're facing? Very few. It's a financing problem now. I went out and I worked closely with terrestrial component suppliers. We turned the problem from one of development to integration. The antenna technology on the airplane is exotic. Once you get behind the millimetric wave, the emissions, into the IF band, into the packets—at the packet level, that's integration of terrestrial components. Then partnering with a very capable company like Raytheon that can look at the antenna technology—that then nullifies some of that development risk there. And the ground station—the gateway—could be a Concentric network. It could be teamed with a company like Concentric.

Question: One comment. The environmental risk of the stratosphere can probably be handled by a hydrogen-fueled aircraft. Lockheed's been working with that since the '60's.

Dr. Nick Colella: I've been very draconian with my company, you know, as a CTO and saying—we're going to do things that are very pragmatic and practical from a regulatory standpoint. That's why we embraced, for example, the Williams fan jets as our propulsion, rather than trying to bring forward a new propulsion technology and getting the FAA to approve it. We've got enough costs for a small company to get the airframe certified and the other systems.

Question: I think Lockheed showed that it didn't take a lot of conversion technique to run the turbo.

Dr. Nick Colella: The 50 gallons per hour, you've got to put numbers in that. My car burns two and a half gallons per hour when on a highway. In the Bay area there are a lot of people like me who are commuting an hour and a half each way to go to work. We're trying to stay conservative here, but thanks for your input.

Dale Tietz: Our next speaker is Bob Ettinger. Bob comes to us with a rich background in military and flight operations—27 years in the Air Force, fighter pilot, flight test pilot, flew 100 missions over North Vietnam. With regard to his aviation background here, he was the chief of the Flight Control Division of the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base, was part of the A-10 System Program Office—director, in fact, and was deputy director of the F-16 System Program Office—culminating his Air Force career as vice commander of the Air Force Flight Test Center, here at Edwards Air Force Base.

With regard to robots, Bob has been working extensively over the last few years as flight director for operations with the Aurora Flight Science team, flying the Perseus and Theseus aircraft. And just in the last 2 and 1/2 years he is THE man working flight test for Global Hawk for the Ryan Aeronautical Center, now part of Northrop Grumman.

Robert Ettinger: I'm going to talk a little bit about Global Hawk and how Global Hawk can be used commercially in all of the things we've been talking about. I'm going to cover some of these subjects and let you see what the platform's like and what its current capabilities are, and then what some of the applications of it might be.

It has a 116-ft wing span. The construction of the airplane is dominated by this big bump on the nose. There's a Ku [band] sat com antenna dish there. There's an aluminum structure on the fuselage; a graphite composite black metal wing and assembly of graphite composite molded together, diagonal tails. The engine comes from Allison Rolls Royce. The core is the same engine that's used on the C-130, 10 decades old. The core of that engine comes from the C-130. The fan wrapped around that becomes a Cessna Citation business jet and on the Embraer 145 [a] commuter jet. The airplane weighs, with a full load of fuel, 25,000 lb, has 15,000 lb of fuel in it. It's a 10,000-lb basic airplane.

The mission looks surprisingly like that chart we saw in the Plenary Session regarding the mission. It's fly out 3,000 miles, stay for 24 hours, fly back. We do that autonomously. We don't have pilots flying the airplane, but they monitor how the airplane behaves. They do that through these communication links. We have a launch and recovery element that's located at the takeoff field. And we monitor the performance of the airplane through a UHF [ultrahigh frequency] line-of-sight link. C-squared would stand for command and control. If we want to change the flightpath of the airplane—say an FAA controller asks you to change the level off or change heading 30°, you can interrupt the basic plan by overriding it through this link or through any of the command and control links.

That link works within line-of-sight. When we were beyond the horizon, more than about 300 miles away on a trip to Albuquerque, we lost line-of-sight link about a beam of Phoenix. Going north we got up about Reno and started losing the link. We used the UHF sat com, fleet sat com. That's capable of talking to the airplane from the launch and recovery element and also from the mission control element. The mission control element is located right now in San Diego. When we're flying missions out of Edwards, we can handoff control of the airplane to the mission control element in San Diego.

In addition to those two command and control links we rely on these wideband links to get the imagery back to the ground. If the airplane is flying over a target area, it can send the imagery back to the ground in near real time. That link is the common data link. It was designed for UAV several years ago. It operates at approximately 150 megabits per second. We throttle it back to about 50 megabits per second, but we send the imagery from the airplane back down to the mission control element in San Diego. From there it's sent by other systems to various image exploitation devices. A suitably equipped user in the field can also get a direct downlink from the airplane over this link. That CDL is obviously a line-of-sight link. To get the imagery back to the ground when you're behind the horizon, we use the Ku [band] sat com. Over every populated area there are Ku [band] sat coms, because they're used primarily for television. We can send the imagery back via this Ku [band] at 50 megabits per second.

Now, when we're flying along, we also talk to local air traffic control agencies by talking on one of these links and having the airplane essentially relay that information to the ground. You receive the information from the ground on the radio in the airplane, and that is linked back to the satellite and back to the control agency, whether it's the launch and control or the mission control element. So there are

four links, two command and control. Actually there are four command and control, because each of these wideband links has a command and control link in it, and then two wideband links for getting imagery down.

So, speaking of imagery, one of the uses for this type of imagery might be to look at forest fires and vegetation from the front of the airplane. Under the front we have an EOIR sensor. This is a picture of China Lake. These are done from above 60,000 feet. This is the boron processing plant right off the end of the runway here. You can see the industrial tanks. This is the ramp at China Lake. There was a little bit of mosaicing problem here. You can see fighters parked here—F-18, some transport airplanes here, helicopter down here. See the cars in the parking lot. The week after this picture was taken, I happened to be on business up there at China Lake, and I drove into that parking lot, put my fingers out like this, and that was how wide those white lines are in the parking lot. You can't quite see them here, but they really do reproduce in the right imagery—the right media.

This is an infrared (IR) picture—same telescope, 10-in. diameter telescope—different collection. There's a splitter in there, and the EO energy goes to this set of collectors and the IR imagery goes over to this set of collectors. If you had enough computational power in the airplane, you could run both of them at the same time. We don't. We usually only run the EO during the day and the IR at night.

This is an IR picture taken during the day. You can see the shadow of a C-130 that was parked on the ramp for awhile and then left. You can see that there was another airplane that was right here and is gone. You can look in the parking lot, and you can see that this car left before this car and before this car, and before all these other cars. So there's quite a bit of scene content in that infrared picture. Another IR imagery. This is the Trona Airport, I think.

We also have a synthetic aperture radar that looks out 20 to 200 kilometers off the wingtip. You can see some baseball fields at Ridgecrest. For some reason, the sensor really picks up that sort of chainlink fence that's used a lot around here. The wavelength is just perfect to show that up.

This looks through the weather. It doesn't matter whether it's day or night or weather, and takes this sort of imagery. This is during a roving sands exercise at Holleman Air Force Base. You can see a mock runway here, riveted areas where airplanes are parked, missile launchers driving along this road, an underground storage area here, and a SAM site over there. There's another close-up of a SAM site down here with six missile launchers around a central van, and then some tells with missiles on them going back to a storage area. Actually, from the storage area they're going this way with missiles on them, and the empty ones are going back this way. A tell is a mobile missile launcher.

The company that I work for used to be called Ryan Aeronautical, and it was just recently bought by Northrop Grumman. So now it's the Ryan Aeronautical Center of Northrop Grumman. Jack Northrop and Claude Ryan used to build things like Lindbergh's airplane and other things together. So they have—the names, at least, have a long history. We were under contract to look at using Global Hawk in the ERAST Program. We did a 4-month study. We looked at possible stratospheric missions for Global Hawk that could be used in the ERAST or scientific area. Looking at the ozone hole over Antarctica is a pretty good task—tropical forests. We kicked this off in a review here. The final report is in work. The final briefing is scheduled for the middle of next month. In addition to the missions we've already talked about, IR, looking for forest fires, using all three sensors on the crop and vegetation, coffee sorts of things, high risk missions, like a winter crossing over the Arctic or Antarctica.

Now I'll talk a little bit about the flight test. We've flown 32 missions. In the beginning the rate of flying was pretty low. It's fly, fix, fly, identify problems. We had to change the engines here because of a problem with the manufacturing of the engines. Our Ship 2 came along and we started flying it, mixed with Ship 1. The rate stayed about the same. As we got the sensor in Ship 2 and we started to prove out, the rate picked up quite a bit. You may have heard about in March, we lost Ship 2 due to an inadvertent triggering of the flight termination system. The Air Force had us have an independent flight termination system on the airplane. We were flying with that on this day, and they were also testing out a flight termination system over at Nellis. The frequency control agency for the western states is at Point Mugu and handles California, and Nevada is done by a different agency. There are no requirements for those two agencies to coordinate, although they usually do. In this case, we're flying along, just climbing out, and on the same frequency (the other agency) turned on the arm and the terminate tone. Our carrier tone actually has to drop off for a real terminate to occur. Just at that time we started to bank, and there was a momentary loss of our carrier tone which allowed their terminate tone to get in there. We lost the airplane. We took 2 months off here while we worried about that.

We started flying again. You can see we're flying at about the same rate we were here. We got Ship 3 in the air. It's flown twice now. This flight was flown the Monday of last week. It was a 25-hour mission. This flight was flown on Friday of last week—another 25-hour mission. So the rate of flying here has started to pick up a little bit. Fifty hours in one week there is one sixth of our total flying time.

At this moment we have 32 flights, 336 hours. In that low slope there the airworthiness flights averaged about—the first 21 flights averaged about 7 and 1/2 hours per flight. We got an average of about 10 and 1/2 hours for all flights. Then these exercises—the last eight flights we've been flying, they've been flown at about 20 hours per flight, average. The last exercise flight, which was last Friday, took off at 1:00 -1:30 in the morning. It flew for 2 hours in the local area here where we get our courage up. Then it flew to Fallon—Navy Fallon up around Reno, spent 12 hours there supporting a combined forces Navy exercise that went all the way from looking for enemy surface-to-air missiles, looking for mobile surface-to-surface missiles, rescuing hostages from a simulated embassy, and close air support on a column of tanks. During that 12 hours we accomplished all those things. Then we left and went to Boise, Idaho and spent an hour in a lap around Mountain Home. We drove over to Salt Lake City and spent 2 hours in the Utah test and training range—came down to the south past Nellis, down to Twenty-nine Palms—spent 2 hours there taking imagery in Twenty-nine Palms, and then back into the Edwards area—flew for 2 more hours and landed at Edwards. Flying two of those long missions is pretty hard on the people supporting the thing on the ground.

On the 19th and again on the 25th we're going to take off from Edwards down here, fly up through here, stay in Fallon for awhile, fly out here by Bend, Oregon, fly up the coast outside the Canadian Adieu, come in here at the Alaskan border, come on up here and spend 3 hours in this orbit taking imagery up by Isleson, and then turn around—come back—fly that route back 2 hours at Fallon, come back into the area and land. Another 24-hour mission. This will be the first time that we've really flown outside of gliding distance to a landing site. The airplane does have a single engine. If the engine should quit when we're over the continental United States, we always stay within gliding distance of a suitable landing site, and that's programmed into the airplane so it'll come down and land on your runway. We haven't had to do that yet.

Question: You don't have to use a chase plane. Is that right?

Robert Ettinger: Well, we do occasionally use a chase plane. First of all, at its operating altitude, it's above 50,000 feet in the first hour. About 3 hours it's above—3 hours—beyond that, 4 hours total it's above 60,000 feet. At the end of the mission it's at 66,000 feet. So there are not many things you can chase it with. If we're going to take off at Edwards in the middle of the day right when all of the traffic is around here, we will chase it. We use an F-16 for takeoff and a T-39 to chase it coming back in. Our agreement with the Joint Use Control Board for this restricted area is that we will sterilize a hockey puck around the airplane within 2515, the closed-in restricted area here. When we're above 40,000 feet, then we fly in the regular restricted area. Our FAA agreements say we'll block altitude from 45 to 68,000 feet, and we leave the restricted area above 45,000 feet.

Question: Can you aerial refuel these aircraft?

Robert Ettinger: That's a bit sporty. If you asked me to do that because I had to, I would trail a drogue out behind that airplane, descend it to about 30,000 feet, and then have a tanker with a probe—a piloted tanker with a probe come up there and stick the drogue, just like all Navy refueling is done, and pump the fuel from the tanker back up into the airplane. That's a relatively low technology way of doing that. Anything else gets pretty hairy, from a technology point of view.

Unidentified Speaker: But the answer is no, we don't currently have that capability of refueling the airplane.

Robert Ettinger: So we don't. Maybe that's because we can fly for 32 hours without refueling.

Question: Basil Papadales from Mirada. Could you describe what the manpower loading is—how many people you've got around when you're flying a 24 hour mission—how many people are supporting the airplane?

Robert Ettinger: Yes. That's a good question. At this stage of the game right now, I put two pilots, two command and control operators in the launch and recovery element to handle the radio coordination to get the airplane off the ground. But once the airplane is up above 25,000 feet, we're handing it off to San Diego. In San Diego I have three teams of two that sit there and monitor the control of that airplane. They work for an 8-hour shift. Presumably, they split that so they're only staring at the tube and watching this thing for four hours each. It gives them a chance to leave the shelter.

Question: From your standpoint, then, there are always two people—either at the launch recovery element or at the mission control element.

Robert Ettinger: Right. It could be that you could get that down to one later in the program.

Unidentified Speaker: The system has also been designed to be able to control three airplanes at once. You have two guys in the shelter to potentially fly three airplanes at the same time.

Robert Ettinger: That's a good point. We really believe that we would be providing continuous coverage over a target area if you flew 3 hours out, stayed 24 hours, 3 hours back. Three hours before you're ready to leave here we launch another one. It flies up there, picks up the orbit, and the other guy is coming back.

Question: Jim Lacey with the Department of Justice. Do you have an estimated cost per hour to operate it?

Robert Ettinger: No. That's part of the NASA study.

Male Speaker: We're under contract. We'll probably come up with a number.

Robert Ettinger: We, incidentally, have a mission planned to be flown in December which takes off from Edwards, flies down the border of the United States to El Paso, and comes back. There are 80 some airfields and about 800 targets all along the border there they're looking at.

Question: Dale Walton. With the issue of the autopilot—as far as pre-planning, mission planning, does that work off of a GPS you pre-plan? You take a floppy out to—some sort of program out to the aircraft, plug it in, download it, and there it works off a GPS?

Robert Ettinger: Yes. Essentially there are two CA-coded GPS receivers that have a differential GPS correction which are used primarily for takeoff and landing at the home site. And then there are two P-coded GPS receivers that are used primarily in flight. We use the Air Force's mission planning system. It's a thing called AFMSS. It's antiquated, and it's not exactly designed for unpiloted vehicles, but we force or fit ourselves into that. We actually plan four mission plans for every sortie. One is the navarete like you see here—pretty simple. The next one has a contingency. If you lose com anyplace along here on all four links, the airplane will—suppose it happens here—will fly to this point, do a tear drop, turn around, and come back. Then if it has a failure, which we call a C-2, a steady, red warning light, a loss of redundancy, it will return to base. It will turn around right now and come back. If something really bad happens like the engine quits, then you're relying on batteries. Or if both generators quit, then it will do what we call a C-3, and it will go to the nearest landing spot. The batteries are guaranteed to last for about 45 minutes. So you have to hurry to get on the ground. But we kind of draw circles about 125 miles in diameter across the ground, making sure we can fly it into one of those places.

Question: Mike Spies. Does it land itself or does it use a remote pilot to land?

Robert Ettinger: It lands itself. Autonomous for takeoff, autonomous for landing. The operator, even when we taxi out and taxi in, it has to do it by pre-programmed coordinates.

Question: And it's all autonomous.

Robert Ettinger: The operator gives it a start taxi and a stop taxi. When it gets to the hold short line, he gives it a stop taxi, gets clearance for takeoff. He gives it a start taxi and taxies out, turns on the runway, taxies down about 300 feet and stops autonomously and waits for takeoff command. Then it flies the whole mission and comes back and it lands. Comes to a stop, and then waits for a taxi command, and it will taxi back in.

Question: Dennis Reinhardt, RMS. You have, and several of the other speakers in this panel have alluded to or have stated directly, that in my interpretation the DoD and the other agencies at the federal intelligence community may be much further along in experience and sophistication than what has developed to date in ERAST. I think that's a given. Can you comment on what the position of the DoD is with respect to cooperation through the commercialization up to the level of sophistication that might be required by the more serious commercial agencies?

Robert Ettinger: You know, the Government—if they thought there was some advantage to exploiting some of this technology that would save the cost of buying airplanes for them, they'd probably favor it. If they thought it was something that's really important from an intelligence gathering sort of thing, they might not be interested in selling it. Pretty obvious.

Question: Are there any weather restrictions for your takeoff and landing?

Robert Ettinger: Well, we have operated to a 16- or 17-knot crosswind right now. We are trying to show that we'll hack it in the 20-knot crosswind—and I believe we will. It's just wait until the wind blows right. We have taken off in a 20-knot tailwind. We've said that's the limit. Initially we said—just to be safe, let's take off toward the lakebed and land from the lakebed. That worked fine, because all our early

flights were early in the morning and there's nobody else around and the wind doesn't blow very much. Lately we've been flying these exercise things. The takeoff time will be dependent on the target time up here where the exercise is. Some of those I've been finding are taking off at 4:00 in the afternoon here, which is absolutely the worst time to take off toward the lakebed. So we have to take off—20 knots is about as much of a tailwind as we want to take. We're going to actually re-plan the thing to take off like big guys and take off into the wind here soon.

Question: Ray Morgan. Bob, you were talking about if you lost the engine, you had pre-programmed airports and emergency bingo points or whatever. Yet you talked about when you take off and land you have a differential C-code GPS. It implies to me that you don't have differential for landing at these unnamed spots.

Robert Ettinger: Of those 32 flights, we have landed on the P-code system about half of the time. It always lands in the center of the runway. No problem.

Question: So you have an accuracy for landing at these fields?

Robert Ettinger: Yes. We believe so. We're not worried about that.

Question: Are these fields military airfields that are designed to accept an unpiloted airplane showing up?

Robert Ettinger: Well, we go to each one of those military fields on that particular route—show them a little video and say— this might happen. This is what it looks like. Here's a checklist. It hasn't happened yet, but we've thought about it.

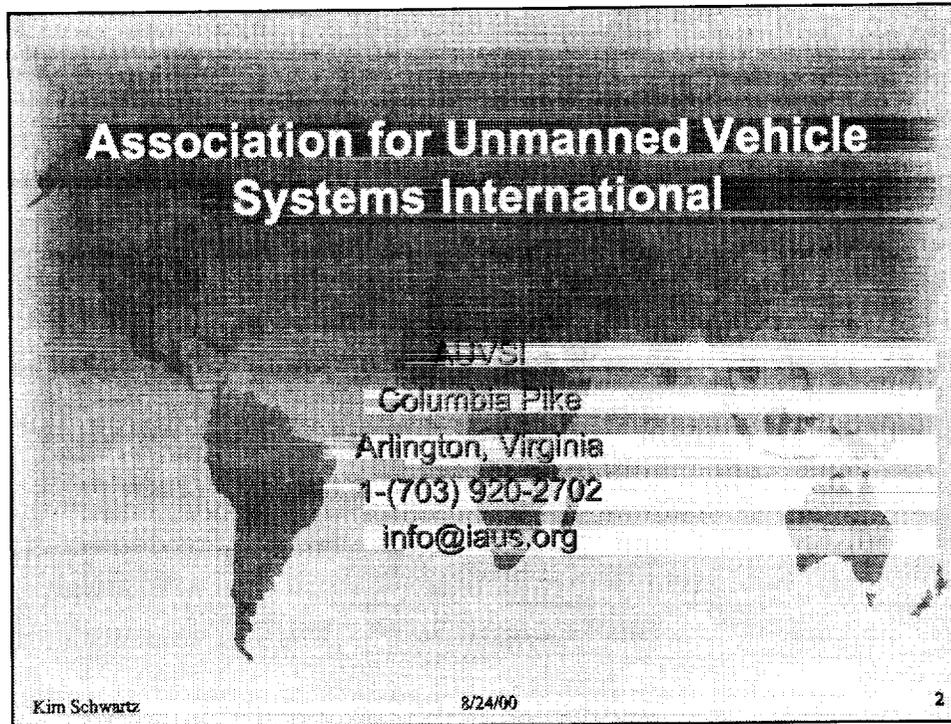
Dale Tietz: Our next guest speaker is Kim Schwartz. Kim is the President and CEO of a company called K Services International. Her company is involved in the development of marketing and sales activities related to military and law enforcement products and services. I think it's especially noteworthy here that Kim is the President of the AUVSI, the Association for Unmanned Vehicle Systems International, which is the large umbrella group that looks at commercial, Department of Defense, and civil missions. It has for some time. I'm informed that there are at least 1,800 to 2,000 participant members of that organization. She is also the co-chair of what Glen Witt and others are involved in now relative to the FAA and it's called the FAA ISG, Industry Support Group. That is an ongoing activity to look at how we get these airplanes to fly in civil air space. Kim is going to give us her perspectives on potential commercial applications for the high altitude.

**Commercial Applications for  
UAV's in the Wealth Extraction  
Market**

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Kim Schwartz: I really appreciate the opportunity to be here. And I have to tell you—from my perspective, in this component of the UAV industry it is nice to see a component of the UAV industry trying to break out of the box with some vision and trying to go after new markets. For a lot of the industry, and particularly the military side of the UAV industry, you get the marketing technique of UAVs for sale, UAVs for sale. I've had more than one UAV business development director say to me, "Well, they know what UAVs are. Why don't they just call us and ask them for them?" So I'm very encouraged. I think this is wonderful that this component of the UAV industry is out there now looking at commercial applications. Because it is the Kim Schwartz view that commercial applications in the future for UAVs is where it's at. That's the real revenue, that's where the real benefit to this technology can be.



Now today I have to wear two hats. I want to take an opportunity to tell you about AUVSI, Association for Unmanned Vehicle Systems International. When I get finished with that I'm going to drop back to the original purpose of my presentation, which is to talk about the potential commercial applications for UAVs in the wealth extraction market, particularly oil and gas, electric power, and related areas. This is not the Bible, but it could be if there was a little bit of funding and effort put forth to proving out the feasibility of this market. You will see that this is an area where there is a tremendous amount of revenue, a tremendous amount of problems, and a tremendous amount of expense related to those problems.

Having said that, I'm going to drop back and put my AUVSI hat on just briefly and tell you a little bit about what this association is about and why I feel that it would be really beneficial if you folks were involved in it to some degree.

## AUVSI (Draft) Mission Statement

To promote, enhance and proliferate  
Unmanned Systems and related technologies  
and services globally, in the following sectors:

- Military;
- Civil;
- Commercial;
- Government;
- Industry;
- Academia;
- General Public

Kim Schwartz

8/24/00

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We are in the middle of putting together our strategic plan. But AUVSI is organized strictly to promote, enhance, and proliferate all unpowered systems in all of those areas—in all areas.

## AUVSI Background

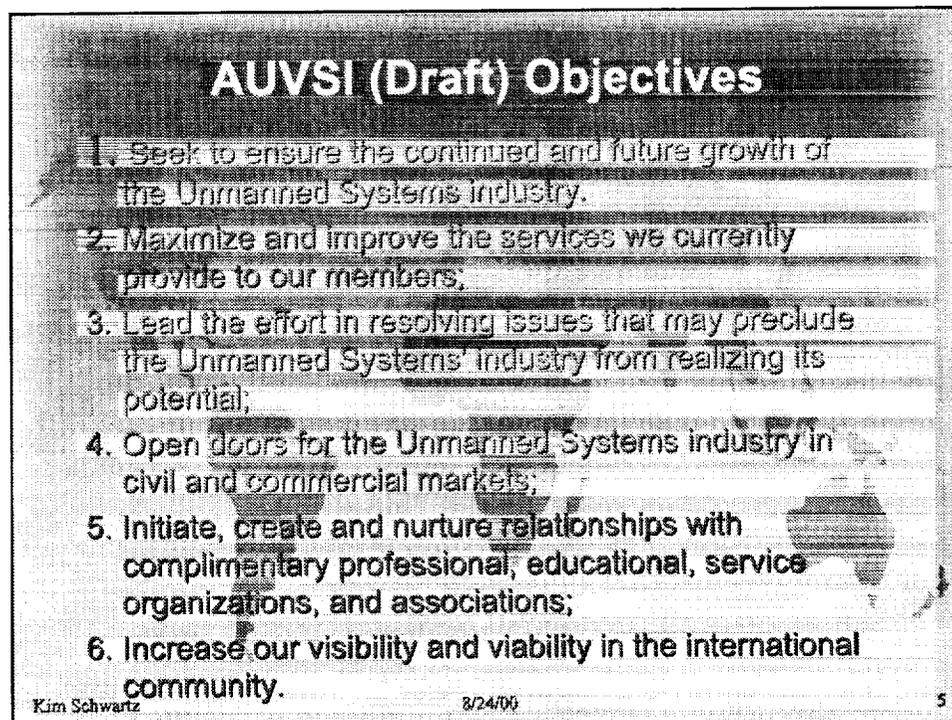
- 26 Year Old Association;
- Represent entire Unmanned Systems community;
- 1500 - 2000 members worldwide;
- Annual Exhibition and Symposia;
- Annual Congressional Roundtable Conference;
- Annual Precision Strike Conference;
- Industry Working Groups - FAA, TRADOC;
- Quarterly Publication;
- Membership comes from industry, academia, government and military organizations.

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AUVSI is a 26-year-old, well-established organization. We represent the entire unpiloted systems community. We have between 1,800 and 2,000 members worldwide. We put on an annual exhibition. We have a congressional roundtable. We do a precision strike conference. We have industry support groups like we just mentioned—the FAA industry support group. We have a TRADOC [U.S. Army Training and Doctrine Command] support group. Throughout the year I'm going to be proposing that we do a few others, such as commercial UV applications workgroups as well as export controls and technology transfer issues support group. I think those are issues that the industry as a whole really needs to get their arms around for us to move forward. We do a quarterly publication. And our membership comes from all over the UV industry.

A slide titled "AUVSI (Draft) Objectives" with a numbered list of six points. The text is somewhat faded and blurry. At the bottom left, it says "Kim Schwartz" and at the bottom right, "8/24/00" and "5".

**AUVSI (Draft) Objectives**

1. Seek to ensure the continued and future growth of the Unmanned Systems industry.
2. Maximize and improve the services we currently provide to our members;
3. Lead the effort in resolving issues that may preclude the Unmanned Systems industry from realizing its potential;
4. Open doors for the Unmanned Systems industry in civil and commercial markets;
5. Initiate, create and nurture relationships with complimentary professional, educational, service organizations, and associations;
6. Increase our visibility and viability in the international community.

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I thought these were particularly key objectives for our association that you need to be aware of. It is first and foremost important for us to seek to ensure the continued growth of the industry, to lead the effort in resolving any issues that would preclude that growth to include airspace issues, export control issues, and others, and to open doors for the unpiloted systems industry in civil and commercial markets where we have not really ventured with zest and gusto before.

## Remote Sensing Applications for the O & G Industry

- ◆ Pipeline monitoring;
- ◆ Facilities and sight monitoring;
- ◆ Mapping;
- ◆ Oil slick and environmental monitoring;
- ◆ Weather monitoring;
- ◆ Resource detection and exploration;

Kim Schwartz

8/24/00

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This information was put together by a team that I organized consisting of experts in the oil and gas industry, and particularly in the security aspect of oil and gas, exports, UAV missions, and international marketing and sales. That's really my background. These particular missions for the oil and gas industry—what we did is we put together a pre-feasibility outline. We interviewed over 20 key executives from the oil and gas industry to get their thoughts on what potential missions ought to be for unpiloted systems. These are the items that they came up with.

Obviously, pipeline monitoring. There are thousands of miles of pipeline on land, under water. They have all kinds of problems from sabotage, leaks, just getting old and breaking. They constantly have to monitor in what they call “run the lines” monthly, yearly, weekly.

Facilities and sight monitoring. Someone was telling me that in South America one oil and gas company has a problem with squatters—people that build camps underneath their pipelines. They have a problem with that on the uninhabited rigs out in the middle of the ocean. Boats just come up and they camp out. That's not very good because it poses a risk for the folks in the oil and gas industry.

Next, mapping; oil slick and environmental monitoring; weather monitoring; resource detection and exploration. Many don't know this—but the oil and gas industry has its own payload. They have their own proprietary payloads that they use for their own proprietary missions. We have been approached about putting together some type of a joint venture to take their payload and put it on an unpiloted system. It's been difficult to find a taker for that, believe it or not.

## Remote Sensing Applications for the O & G Industry

- ▶ Power line inspection;
- ▶ Periodic photographing of facilities for security purposes;
- ▶ Investigative operations;
- ▶ Mine detection;
- ▶ Gas leak detection;

Kim Schwertz

8/24/00

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Power line inspection. Another customer at a Latin American oil and gas company, power company said to me, you know, if you had something that could fly into the most remote areas where they have all these powerlines draped and that could detect the difference in resistance before the powerline broke, that would save us millions of dollars a year.

Periodic photographing of facilities for security purposes. Investigative operations. One of the security officers was telling me, "If you could put some type of a thermal imaging device on that," he says, "we know when we're being ripped off. They'll have trucks come up to rip off the oil or the gas out of the lines. We could stake out the area with an airplane and watch them come in. With a thermal imager you can watch the flow of material go from one to the other and nail them." Apparently this happens all the time.

Mine detection. What does an oil and gas company have to do with mine detection? Well, when you're putting pipeline in places like Angola and Afghanistan, you have to worry about mine clearing for your people.

Gas leak detection. This is a huge issue in the oil and gas industry. One company told me, "For us to do ground operations for a relatively short amount of pipeline—it's a \$300,000 proposition for a fairly short amount of pipeline to determine leaks." If we could [only] do that from the air. We do have payload capability to do that from the air. They also do leak detection under water. Apparently there are sensors that can do that too. He also said, "If you could do that, that would save us billions of dollars a year." They call it the vanishing gas problem.

## Rationale - UAV Industry

- ▶ Commercial procurements not dependent on defense budgets and federal acquisition procedures.
- ▶ (Should be) Less expensive to produce.
- ▶ Could provide Co-production opportunities, and be incorporated into a successful offset strategy in support of foreign military UAV procurements.
- ▶ Commercial platform could provide initial market presence in desirable markets for military UAV's.
- ▶ Establish precedent for future technology export / transfer issues for military UAV's.

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I put together some rationale for the UAV industry—why this makes sense. This is focused on commercial UAV's but also on military UAV manufacturers. I realize that the military UAV manufacturers and the commercial ones compete to some degree. But just like Lockheed Martin and Boeing—can't we find a way to get along? They do find ways to work with each other. Some of these points might suggest that there are ways of collaborating with your more militarily focused UAV manufacturers if we sit down and put our heads together. I'd have to get into an entire lesson on international marketing and sales to go into that, but I'm going to hit some of the highlights.

Commercial procurements are not dependent on defense budgets and federal acquisition procedures. I consider this a bonus. Commercial UAV's should be less expensive to produce. They could provide co-production opportunities and be incorporated into a successful offset strategy in support of the foreign military UAV procurement. Does anyone in here know what offset is? In most foreign countries if you sell a million dollars worth of defense item, you are required to put either 50 percent of the value of the procurement back into the item that is being purchased or invest 50 percent of the procurement in business initiatives in the foreign country.

Commercial platforms could provide initial market presence in desirable markets for military UAV manufacturers. This is true because it's going to take a lot less time to get a commercial UAV in a foreign country than it is a military one with the military payload. You've got market presence before you try to get your military bird in there. We have a lot of work to do in this department down here. It could certainly help establish precedence for future technology export issues.

## Why do UAV's make sense for the Oil and Gas Industry?

- ◆ Pipeline security is overhead and equipment most intensive. Millions are spent each year monitoring pipelines, storage tanks and pumping facilities.
- Acts of terrorism and sabotage cost the O & G industry millions each year in damage, lost revenues, and lost lives.
- The prevention of one downed power line for one day could save as much as \$ 1M US, in S. America.

Kim Schwartz

8/24/00

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But, more importantly, why do UAVs make sense for the oil and gas industry? Pipeline security is super overhead and equipment cost intensive. Millions and millions are spent each year on monitoring pipelines, storage tanks, and pumping facilities—besides being dangerous for the people that have to do it. Acts of terrorism and sabotage cost the oil and gas industry millions of dollars each year in damage, lost revenues, and lost lives. As an example, the prevention of one downed power line—just one downed power line for one day could save as much as \$1 million U.S. And that's in Latin America. The magnitude of the losses that could be prevented with UAVs that gives you some leverage right there.

## Why do UAV's make sense for the Oil and Gas Industry (cont.)?

- ◆ Increasingly, pipelines are being located in world trouble spots.
- ◆ "Vanishing Gas" costs the gas industry billions each year.
- ◆ The losses suffered due to environmental damage are the greatest.

Kim Schwartz

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Increasingly, pipelines are being located in the world trouble spots. I've got a few facts and numbers for you to support these bullet points. Vanishing gas costs the gas industry billions each year. One of the companies that I spoke with said that [for] his company alone—the cost is approximately \$8 million a year in lost gas. Think of all the oil and gas companies out there and how much money's being lost in vanishing gas. However, they told me that the losses suffered due to environmental damage are the greatest. No numbers were given, but I think it's more related in fines and legal costs.

## O & G Hotspots - Intl., (cont.)

- ◆ **Caspian Basin (Azerbaijan, Georgia, Armenia) -**  
"The real issue is how to get oil to market from a land-locked sea overshadowed by the planet's bully boys, and across a mountainous region fraught by ethnic strife, banditry, and small wars."
- **Chechnya -** "Chechnya sees pipeline security as task." Guards are stationed at 1/2 mile intervals along pipelines to guard against sabotage.
- **Turkey -** "Militants...sabotaged part of the Kirkuk-Yumurtalik oil pipeline...", resulting in losses of about TL 4 Billion.

Kim Schwartz

8/24/00

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In the Caspian Basin, the real issue is how to get the oil to market in a land where there are terrorists and people who seem to focus on disrupting oil supply. In Chechnya, the quote is "Chechnya sees pipeline security as a task." But they, in fact, have guards stationed at half-mile intervals to keep people from blowing up the pipelines. In Turkey, this happens on a quarterly basis—that they will sabotage a part of this pipeline. Every time they do that it's major losses of four billion in Turkish currency.

## O & G Security Hotspots - Intl.

- ◆ **Colombia -** "Oil Companies Buy an Army to Tame Colombia's Rebels". The oil industry, private and state owned, lost almost \$ 1B over 4 years, from sabotage.
- **Algeria -** "Troops said to kill 49 Moslem rebels in Algeria". Anadarko had to close down offices in the capital after Islamists declared they would target foreign workers.
- **Nigeria -** "Shell plays for high stakes in Nigeria"

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The oil industry—private and state owned—in Colombia lost almost a billion dollars over 4 years just from sabotage. This happens on a very regular basis that people are getting killed in Algeria over pipelines.

## O & G Hotspots - Intl., (cont.)

- ◆ **Afghanistan / Pakistan** - This is a development...which has been held up by the war between the Taliban and its opponents.
- **Chad** - Plagued by several periods of civil war, a succession of military coups, numerous conflicts between paramilitary groups, and an extended military conflict with Libya.

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Just some bullet points to show you that where all the pipelines are going in the world there are huge problems with keeping the oil and gas company employees safe and the pipelines in tact.

## '97 Pipeline Security Issues - US

Type	Barrels	Prop.	Fat. / Inj.
Lost		Cost	
Haz. Liq.	163,792	\$ 36.8M	0 / 5
Trans. &			
Gathering		\$ 11.6	1 / 5
Distribution		\$ 12.3	10 / 80

Note: Accidents due to "outside causes"

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This is in the United States, and these are 1997 figures. But these are losses due to sabotage right here, which are fairly significant—the loss of life.

## New Pipeline Projects

Countries	\$	Mi.
Chad - Cameroon	\$ 3.0B	650 Mi.
Algeria	\$ 2.9B	
Baku - Ceyhan	\$ 2.5B	1,081 Mi.
Afghanistan	\$ 1.9B	1,462 Mi.
Sudan		1,500Km
Kazakhstan	\$ 9.5 B	

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## New Pipeline Projects

◆ Countries	\$	Mi.
➤ Azerbaijan		1,780 Mi.
➤ Middle East (13)	\$ 80 B	
➤ Qatar	\$ 4B	
➤ Turkmenistan	\$ 4B	
➤ Uruguay	\$ 200M	

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New pipeline projects. These all equal out to be about \$1 trillion. But as you can see, the pipeline projects—the big ones—are all in the nasty garden spots of the world. The assets to be protected are immense.

## Present Methods

- ◆ Companies use a combination of primitive aerial platforms (USAF O-2) and sensors from the AC-130 vintage 1976 (generation 1-1/2). These systems tie into a maritime or land security force.
- Information is not real time and is ineffective in anything but a crisis situation.

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Presently, oil and gas companies are using some fairly primitive methods of obtaining data—O-2's and 130's. They tie them into a maritime or land security force. For the most part their information is not real time.

## The O & G UAV Advantage

**UAV's would:**

- ▶ Provide longer duration over target, more flexibility, better response, and lower risk.
- ▶ Allow for a reduced ex-patriot population, and minimize no. of personnel in harm's way.
- ▶ Decrease monitoring costs, and increase surveillance capability.

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So we think, and the folks with the oil and gas companies that we've talked to on a peripheral basis have said that they believe that UAV's would provide longer duration over target, more flexibility, better response, and lower risk. They would allow for a reduced ex-patriot population in some cases, not in all cases. But they would minimize the number of personnel in harm's way. That's a really key point with the oil and gas industry, is minimizing the personnel in harm's way. They would certainly decrease monitoring costs and increase surveillance capacity.

**O & G UAV's - Integrating into a Security Force**

**The best approach for integrating UAV's into an O & G company's security force is to provide a total package plan.**

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Finally, the consensus of these folks was—we don't want any more gadgets and gadgets and gizmos. We need a total package. They're not interested in buying a UAV. They're not interested in buying the logistic support. They want the package deal. The way to do this is to come up with a leasing type of a program that provides them the platform, the training, the logistic support, and everything goes with a one line item—to find the way to do that. I think that's it. For commercial applications for UAVs domestically and internationally, we're not going to be able to do anything until we get our arms around the airspace issues and the export issues. And that's what we need to do as an industry as a whole.

I would like to put my AUVSI hat back on again. I'd like to encourage all of you to support the FAA industry support group effort. We do have a meeting next week in Las Cruces, New Mexico.

# Charter for FAA ISG

## Mission Statement

- ▶ Assemble an Industry Support Group to prepare a family of requirements based concepts for commercial operations in non military controlled airspace.
- ▶ Characterize, Prioritize, and Project business opportunities.

Kim Schwartz

REV 20  
8/24/00

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This was our charter. To assemble an industry group to prepare a family of requirements, base concepts for commercial operations in non-military controlled air space. The tie-in with what I'm talking about is that the one thing with the FAA is this kind of a catch-22. They've said—show us the money. Why should we spend any time, we've got all these issues to deal with. We don't have any money. You need to show us that there's commercial business out there for us to be able to pay any attention to it.

## 3rd AUVSI FAA Industry Support Group and Workshop

Sept. 18 - 19

Sorrell Center

New Mexico State University

Las Cruces, New Mexico

Register online at

<http://www.psl.nmsu.edu/roa>

or contact

Diana Kovar

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So it's very important what you're doing here with ERAST. It's very important that we all get our arms around the airspace issues, but we do it collectively as an industry.

Question: You mentioned there are payloads existing for doing some of this observation of pipelines and powerlines, and so forth. Do you know anything specifically about how close you have to fly them to the pipelines and powerlines?

Kim Schwartz: No, I do not. This was a pre-feasibility survey. The project ended there. But there are payload manufacturers. I do not know how close you have to fly.

Question: If you flew over a pipeline and observed people trying to sabotage it, how would that help you? You'd still have to have people there to stop them.

Kim Schwartz: You would have a real-time transmission of the problem back to the base. Assuming that there was an army ready and waiting to go out there and get them, that is much quicker than the situation that you currently have. It would also tell you how many people were out there. It would tell you what kind of weapons they had so you could be prepared when you went out there.

Question: But they'd still have to maintain that militia that was nearby or they wouldn't be able to stop it anyway. Right?

Kim Schwartz: They do that in Colombia and other places. It's just like the police. You can't stop it. But, again, it's knowing what the situation is before you go in that can determine the effectiveness of how you resolve that situation.

Question: I know they do powerline inspections—just fly aircraft down. I mean how does this compare, particularly domestically?

Kim Schwartz: I often get asked a similar question with regard to ex-patriot pilots. When I contacted a CFO of one of the majors, he said—"we just lost a pilot last week. I don't want that to ever happen again." It was from pilot error. It wasn't because he was shot down or anything like that. Our people are important to us. And losing one of them is not worth the risk. I've heard that echoed all over the industry. I've also heard from another security guy I was talking to about other countries and how you have to worry about being shot down. He said, "we have them coming in with bullet holes in them all the time here in the United States." So to the oil and gas companies, ex-patriot risk is not acceptable, I learned that when I went. I didn't expect that to necessarily be the answer.

Question: Ron Schramm. If you're looking for a financial model to lease an aircraft, it's one thing to fly locally or to fly a non-combat zone where you can get hull insurance. You need to get hull insurance if you're flying in hostile territory. So your assumption is that of replacement costs?

Kim Schwartz: That would certainly have to be looked at. But based on the amounts of damage that can be done and the losses in resource, that's part of it.

Dale Tietz: Our last briefing is going to be on a very interesting topic. Interferometric synthetic aperture of radar technology as it applies to potential commercial applications. Harold Malliot is going to give us a briefing on the subject. He comes from an extensive amount of research development background on the technology side from Lockheed Martin Missiles and Space Company Research Labs in Palo Alto. He's done a lot of work in this area on many different aircraft. It's directly applicable to what we're talking about here—the SR-71, the ER-2, the U-2, the Egret, DarkStar, and Global Hawk, and the plane that I think we're going to see a little bit more of which will be the Canberra.

Harold Malliot: [Slides unavailable] There's a quest for 3-D[imensional] imaging. Many approaches in optical area, in stereo photogrammetry, laser ranging, laser holography, and the newer technologies over

here—microwave. The area in particular that's the most effective in this is called interferometric SAR. SAR is synthetic aperture radar. I'm going to describe this to you today—how it's used, and so forth.

The primary objective of all this is to provide the third dimension. But first let me show you what microwave or radar does for us. First of all, it gives us immunity to weather problems. In other words, it's an all-weather capability. You don't have that with optical systems. You provide your own energy. You can propagate through very dense, even storm media with very little impact on it.

The microwave systems provide a different type of information than optical systems. It turns out they're very synergistic to it. Rather than being dependent on reflectance and emissivity characteristics like it is in the optical and infrared region, the microwave systems respond to the roughness of the surface. That's the electrical property as the medium. It provides a great deal of information that is not contained in optical images.

One of the most important values of this technology, though, is that in radar images the phase information of the signal is present. You don't have that in optical images. But in the radar image we have the phase information. This is what makes the images useful for getting elevation data. Very powerful techniques.

Here, for example, are some thematic mapping images and a radar image. It provides a considerable amount of information, including structural information, as I mentioned before. When you look at these different areas, physically there's different phenomena involved there. Synergistically then, you can gather more information from a remote sensing point of view. Very powerful combinations.

Let me go into what synthetic aperture radar is and then what IFSAR is. Then I'll go into how it would be integrated into an aircraft. Fundamentally, our basic radar generates a beam like a pencil. That beam intersects on the ground and makes a footprint on the ground. In range it resolves an area with a width here, depending on the bandwidth signal—[at] 300-megahertz bandwidth you have a half-meter resolution. The length of this resolved area is determined by the width of the beam here. So with its typical radar at, say 50,000 feet, you would have a point here maybe—a resolved area here maybe half a meter in width—in range direction, and almost a kilometer in the long direction. Not very good for imaging, of course.

That problem is resolved by the synthetic aperture radar technique, which processes the Doppler history of the signals as the radar is moving. This is very simple to think of in terms of when you listen to an ambulance go by. You hear the Doppler shift—high coming toward you, low going on the other side. Now if you have two ambulances coming by simultaneously, theoretically you could tell the difference, and you can actually locate them in space by a difference in resolution, I should say, as proportional to the bandwidth of those Doppler shifts. That's how synthetic aperture radar works. It compresses this long, azimuth-resolved area in the beam down to a very small area here. There are several advantages to that, not only the resolution itself, but the fact that the resolution is independent of range. I can resolve just as well at an altitude of 50 feet as I can at an altitude of 50,000 feet. It's independent of range.

Another advantage of it is the signal strength is a  $1 \text{ over } R^3$ , rather than  $1 \text{ over } R^4$ . So it's a huge energy savings and reduces the amount of power you have to transmit. Of course, that directly impacts the vehicle power generation. For example, C-SAT-A in orbit only required 55 watts of average power to generate all its images.

I'm going to talk about topography in terms of digital terrain matrix and digital surface matrix. I wanted to show you what the difference is. A digital terrain matrix is the actual bare earth—the ground. The way it's measured is from some datum. For example, the WGS-84 ellipsoid, if you're using the GPS system as a reference. You're measuring the height from that reference—ellipsoid. Now if there are objects on the surface—buildings, trees, cars, what have you, the radar, just like the optical system, sees the object. So you don't see the surface under there—you see the object. So there's a difference, and that's a problem. It's a problem for virtually every imaging system. There is no imaging system presently in existence that can give you a true terrain topography. Looking from a realistic point of view, if you've got a building there, what is the terrain under it anyway? They have a big hole dug underneath it for a basement, and so forth. The point being is that the digital terrain matrix is a digital file of periodic points along the surface where the elevation is measured. That's data stored in a digital computer disk. Then you use it in processing remote sensing data and GIS systems, to give you to the third dimension. It becomes your bottom base, I should say, for your whole GIS or image processing system. That third dimension is extremely important in all the remote sensing applications to get the geometric effects of the terrain into your remote sensing applications.

Now if you take the SAR image, which is an image formed as radars float along, and it's measuring these pixels in range and out, and compressed down an azimuth and it forms an image—very much like an optical image. In fact, you take a SAR image that's been geometrically corrected and lay it over the optical image, and they correspond very close together. In fact, you can use that to transfer points between the two images. If you take that digital surface matrix or DTM file with computer processing, then you can generate perspective views. Actually, you can do fly-throughs. We've done this very effectively by taking the DTM data from an IFSAR system and overlaying a photographic image on it and getting a three-dimensional photographic image then that you can actually fly around in. The greatest example of this is the Magellan radar that was used to map Venus. It generated 3-D images or a terrain topography of Venus. In fact, we have more complete knowledge of the surface of Venus than we do of the Earth.

Now one of the techniques for getting the 3-D image by radar is a technique called stereo SAR, which is very similar to stereo photogrammetry. You take two views of the scene. Here is Mount Shasta viewed from two orbits – SIR B-sensor B, one at an elevation of 20°, one at an elevation of 60°. You use stereo photogrammetry and you can get elevation contours on that image. Then you take color data from the image and you color code this. Remember the intensity of the image is proportional to the surface roughness. But you color code that—it gives a little bit better eye appeal with the intensity and the coloring—and put that together with the topographic data, and you get a perspective view. I can show you images all the way around Mount Shasta made with these two passes of SIR B. It's very much like stereo photogrammetry. But it's not really the best way to do it for radar.

The next level of system is what's called SAR interferometry. That is, you fly and make a SAR image in one pass. You do your SAR image processing. That generates that SAR image that looks like a photograph. You make a second pass, either with the same aircraft or another aircraft, or whatever. You take these two and process them together. Each pixel in the radar image has a phase. So I take the difference between the phases of those two images, and I get a phase difference image. That image looks very much like the fringe patterns you get if you looked at a Mack zender interferometer, look at the contour of the surface. It's a bunch of inner fringes. You do some processing on it, and you generate the DTM data from that.

Here's an exchange of 2.8 centimeters. You can measure range changes in the order of millimeters. These have become extremely sensitive.

Now if SAR is interferometric SAR rather than SAR interferometry, and the difference is rather than taking your two SAR images one after the other you take them simultaneously. There are some very significant advantages to doing this. If you take those two images separately, number one, there have been some temporal changes in the scene. Even if you delay taking them a few minutes, there are some temporal changes. The leaves on trees move, and so forth. The atmosphere is different. You've got atmospheric—you have refraction effects, and so forth. Now if you do those simultaneously with the two SAR receivers translated on the same aircraft, the atmospheric effects drop out because both images have the same turbulence effects in them. There haven't been any temporal changes because you've done them simultaneously. So you end up with a much more effective, much more coherent relationship that allows you much higher precision in extracting the elevation data.

Now how do we extract the elevation data from that? We're looking at the groundpoint down here at some elevation  $H$  relative to our datum, with a receiver located out here on this end of the wing and a receiver located here on this end of the wing. We've transmitted a signal from somewhere along here, or maybe the fuselage. It doesn't matter much. The important issue is that radiation scatters off the surface and is received up here and propagates over here. And because the ranges are different there's a phase difference between them. Remember, I said you can tell the phase difference in the radar image. So you process the images on a pixel by pixel basis, and that range—that phase difference is proportional to this angle here. There's proportional range difference that is also proportional to that angle there. So that gives you the elevation angle. Through simple trigonometry, if I know the tilt of the base line, then I can compute  $H$  with very simple trigonometry. That's simply how 3-D SAR imaging works. There's a lot of very complex processing goes on in it. But that's the bottom point.

Now IFSAR has been evaluated very extensively for its utility for topographic mapping and general terrain elevation gathering. Over a 2-year period USGS conducted an extensive analysis. The Army Topographic Engineering Center has completed an analysis, comparing the techniques with stereo photogrammetry and laser range finders. Voxel, Inc. did a study funded by DARPA as part of the IFSAR-E program back in the early '90's. They all concluded that IFSAR is the best way to generate topography. It gets you the largest area coverage. It gets you the highest quality data. You can do it without tie points. Because you can integrate this data with GPS, and you don't have to generate tie points—a very expensive process in 3-D imaging.

Back in 1996 I went out and spent a couple of weeks with Darrow, helping them do a study of alternative platforms for doing the high precision—what's called DTED-5 data collection for the DoD. We evaluated all these different concepts here. I mentioned a modified U-2R here. That actually was an ER-2, NASA's ER-2 that I developed a system called D-Tems on. You compare the area coverage capability with all these, and so forth. Even with the SR-71's—you know how fast it is compared to all the others. Look at the modified U2-R or D-Tems [it] actually does as well at a fraction of the operational cost, and so forth, but it gets much better accuracy. The Canberra system, which is a system the high-altitude mapping missions is developing, we will be able to get about 30-centimeter average elevation accuracy and we'll be able to map the entire United States in 3 months. That's how much area coverage capability we'll have. That's at a leisurely pace of three flights a week. This system will be able to collect 200,000 square kilometers in single flight. That's half of California on a single flight.

We have a DTM made on one flight, a DTM made on another flight. We can look at the difference between those and see changes in them. We see centimeter level elevation changes. Very important for disasters. I've already flown over and mapped the area. You've got a hurricane going on, and I can fly over it and I can tell you if there's slide, if there's flooding, if buildings are knocked down because of change detection. There are a couple of ways of doing it. There's another technique called coherent change detection, which is extremely sensitive. That technique is so sensitive that for your security issue on the pipeline—I can see the guy's footprints that walked up and put the bomb there. This is from 60,000 feet.

You can detect lateral change motion by taking groups of image pixels and cross-correlating them from two different passes and measuring the actual translation on them. You can measure translations or centimeters—extremely powerful for looking at volcanic activity where you've got volcanic bulging, seismic activities along faults—you see the faults moving or slide areas, subsidence, all kinds of land movements, erosion—all kinds of things where land is changing. You can actually measure these changes very accurately.

As far as commercial products are concerned, here's a gray scale image of DTM data. These data actually would be stored on a hard disk as bytes of data representing the height in the standard format—like USGS uses a line scan format. The ortho-image is the SAR, which are very much like the optical images, and then the SAR correlation data, which tells us about the changes that have occurred in the image. All very valuable data for various remote sensing applications.

Value added products, where the big money is, will be found in producing digital maps, true topographic maps. I'd like to compare what we can do, for example, with a Canberra SR, and potentially with a UAV. USGS topographic data are 30-meter post basing; that is, the points measured on the ground are 30 meters apart. You can have a hole that a Mack truck can drop in. You ought to know about it. The elevation accuracy is 5 to 7 meters. That's how much area you've got. That's why FEMA is being challenged about their flood maps. Because they're going to tell you you have to have flood insurance or you can't build a house somewhere. The data they use are sampled 100 feet apart and have an error of 15 feet. So that's why they've got to do a map modernization, which is going to cost them \$800 million. They're projecting the cost of it. We can collect the data for the whole United States at a total operational cost of \$1.5 million. Big technology change. Classification maps in which you identify things in the image, like finding roads, and so forth—all the types of things you know about classification. And then, shaded relief maps, which are very good for eye appeal that brings out things.

These images can be displayed in several forms—as shaded relief, color-coded elevation, or perspective views.

I mentioned before digital surface matrix versus digital terrain matrix. Well, here's an example of separating the two. Here is the area where, actually, you've got the surface things—buildings and trees, laying over the terrain. For this area here he's pulled a lot of the surface stuff off and shows the underlying terrain. So you can actually separate these and find the true bare earth beneath some of the surface stuff.

How do you do it? Well, first you need an air platform. You need a SAR—and a SAR with two receivers that are looking crosstrack from different displaced crosstrack from relative to the direction of motion. Differential GPS systems. Good flight operations, in particular, operating at high altitude where you're above air traffic control and you don't have to go through storms, because this is very sensitive to

disturbances due to turbulence. Up above the troposphere is where you want to be. With the SR processing you generate those data archives. You use that DTM data then to rectify, that is, geometrically correct the SAR images. So now you've got a geometrically corrected SAR image. And who's the big market? What are the biggest markets? Satellite imaging firms. Space imaging can save 90 percent of the cost of producing rectified images by taking our DTM data and using it to ortho-rectify their images. Now, an ortho-rectified image is worth, in some cases, ten times an unrectified image. So you see big, big cost effectiveness here in doing this.

What are some of the issues that become involved here? Well, multipath off the aircraft is a very important issue. So structural organization of the aircraft and/or an aircraft design that doesn't reflect, like carbon composite. Your carbon composite UAVs are really good in this respect because you don't get multipath off them. You like high speed. So we would want an aircraft that can do Mach 0.6 to Mach 0.7—high altitude, 50,000 [feet] minimum on up, because that maximizes our area coverage. High stability, so we're not having to deal with the residual air, in motion compensation [that] is proportional to the magnitude of the disturbances you have. You would like as high a stability as you can get. Long-range capability. You'd like to be able to have collection periods of 5 hours, actual on-line collection times of 5 hours. High reliability. We don't want to have to abort missions, and we want to be able to takeoff when we're supposed to.

There are many error sources involved here in the IFSAR instrument—the IFSAR processing, systematic errors in the geometry in the system, and so forth. And these are all handled by very careful design, understanding the physical relationships, and designing the system to minimize these errors. The single biggest factor that minimizes the error, however, is baseline—the separation between the antennas. If you get an aircraft that you can maximize the antenna separation on, you've minimized the phase error in the system.

Here's an example of a distribution of error for a crosstrack. The blue lines are [data] collection on two sides flying in one direction. The red lines are turnaround, comeback, offset, and flying in the other direction in order to cover the gap. It ranges from less than 10 centimeters up to on the order of 40 centimeters in elevation error. You can't get that by any other means. Even laser range finders can't do that for that large an area.

Major issues—multipath, reflection off the skin here and the skin here, and double bounces off the wing, are big problems. Those are avoided by having a good aircraft geometry and carbon composite designs—very good for that.

This just shows the magnitudes of the phase errors, how they depend on things. It's very sensitive to them, and you have to design the composite for that.

Conclusions. A UAV may be a useful platform for limited commercial IFSAR applications. Is there a market for IFSAR products? What that really translates into is—given a UAV and the integrated capability of an IFSAR with that UAV, can you produce a product at a cost and a quality that can meet the market demands? That's the issue. All the IFSAR, GPS, and data handling and processing software and hardware exist. There's no technology risk here. Integration of the systems onto the UAV is the challenge.

Area coverage and operations cost will be important parameters. You've got to have an aircraft that can be operated economically. From what I'm hearing here, the UAV doesn't sound too good. I'd rather see the pilot in there. Because what I see is the cost of flying unpowered vehicles looks to be pretty high. The most

important issue, though, is the area coverage because the maximum range extent you get from your ground control station is small. However, there's some special niche market that they may be very valuable in, that uses a spotlight mode SAR, which generates even a higher resolution and accuracy than I've talked about. That would be applicable to small areas, and some of these vehicles would be useful for that.

The bottom line is I'm willing to evaluate potential vehicles. Give me the data on your vehicles. I need all the structural dimensions on the vehicle—its carrying capacities, its speed, its function of altitude, and so forth. I have very complete analytic codes in which I can evaluate the performance on them with. If there's a winner there, we're willing to get into alliances to develop this.

Let me say one final thing here. You want to sell aircraft. But who's going to buy your aircraft? I'm not going to buy your aircraft unless I can get a product from that aircraft that allows me to generate a huge amount of money—that stockholders are going to buy my stock to look for a big IPO payoff. That's the bottom line. I don't even want to own your aircraft. I don't want to operate your aircraft. My business is producing data, not operating an aircraft. So you aircraft suppliers have to come up with a model—and I'm not the only one. The communications guys are the same here. You have to come up with a model that meets our—as users of that technology, our needs. I think the best way to do that is the manufacturers have to look at it as you're going to sell a vehicle, you've got to get into an alliance. You have to look at this corporation, this startup company, as a big payoff, and make the investment in the company and help that company get the financing it needs. And then you're going to sell, you're going to make money then. You're going to make money off that product through the growth and the sales of that company.

Question: Jerry Peterman, Direct Wireless. I'm interested in knowing if ground-penetrating radar falls into the same realm as SAR in its synthetic aperture. Is that possible?

Harold Malliot: Yes and no. Ground penetrating radar ranges—it depends on what you call it. The simplest form of ground penetrating radar is a little pushcart you put on the ground and it transmits an impulse. They call it a ground penetrating radar. I don't call it a ground penetrating radar. I call it just an exotic metal detector. In fact, the surface penetrating SAR you're talking about—there has been one built, one flown, one worked effectively, saw deep down into the ground, but it wasn't the Earth. It was done on Apollo 17 with HF antenna—HF Yagi antenna that looks very much like the old TV antennas, pointing down from the command module. They did lines along the lunar surface, and they looked down into the lunar soil on Apollo 17. Yes, you can see down into the soil somewhat. The problem with the ground penetrating radar is when you have soil moisture, the extinction is extremely large. With, say, 20-percent moisture in the soil, you'll get 100 dB attenuation round trip. It's a huge loss. But the big problem, and this gets into the P band systems that DARPA is recently building. I've kind of picked jokes at GPL for this for a number of years and say it won't work. They're trying to get down from the surface of the trees—top of the trees. X-band scatters off of the top of the trees. They want to get down through that to the ground to see the bare earth. P band 425 megahertz tends to go down through there. Doesn't go all the way because it rattles around off the tree trunks and branches and comes back up. But worse than that, it goes down and hits the ground and penetrates into the ground. Well, in the conductive median what the ground is when it's wet the wavelength shortens. It's meters long ordinarily. When it gets in the ground it shortens like this. It just has to penetrate a little ways, and you've got a great big phase change. We're measuring phase difference. So we've got a huge phase error that we can't predict because we don't know the moisture in the ground.

Question: The question was based on a steady desire to find antiquity sites in the Sahara, sub-Saharan area.

Harold Malliot: Yes. That has worked. In fact, they've seen them. They've seen old river bottoms and trails and stuff there. That's been with the L band radar. It's because the soil in the Sahara is so dry. It's just dry sand—quartz. The L band quartz is very transmissive. So it goes down until it hits that old soil down there that's clay, and then it reflects back. So that's what you see.

Question: The Canberra was the aircraft Lockheed converted to hydrogen fuel. Were you burning hydrogen fuel? It tends to enhance range and endurance.

Harold Malliot: No. These Canberra that we have were owned by the British research agency that's our electronic warfare outfit. We bought them from them just a year ago. They were built in the '60's, but each has about 2,500 hours, total hours on them. Never been used. They've been stored in hangars all their lives.

Question: One of them burned hydrogen.

Harold Malliot: No. Not these.

Question: The early ones in the '60's.

Harold Malliot: Yes. Not these. These are Avon 109 engines.

# **SCIENCE WORKSHOP**

## ERAST-MEZZANINE SCIENCE WORKSHOP

### Expectation



#### *Stimulate New Concepts for Airborne Science*

- *Highlight Earth Science Landscape*
- *Expose Potential UAV Science Mission Roles*
- *Share Real World Experience*
- *Get your feedback*

*Steve Wegener*

Steve Wegener: My name is Steve Wegener. I've been with ERAST since before the beginning. I started off with the Perseus A aircraft, trying to support the atmospheric effects of the aviation program, trying to fly higher than the ER-2. Science has been a driver for ERAST since the beginning. I've tried to represent the customer to ERAST to talk payloads, mission planning, interface activities and such. Over the years ERAST has expanded to many platforms and continues with a science thrust.

Today what we're trying to do is to talk about possible new concepts for airborne science. We've brought together speakers to try to highlight what the earth science landscape is like—what the big science questions might be from a NASA Code Y perspective, to expose some of the potential UAV science roles, mission roles, that might be out there, and draw on some real world experience from folks who have worked with UAVs in science missions. And then lastly, to get your feedback.

# Agenda



2:00 - 2:20	Introduction,	Steve Wegener
<b>Science Landscape</b>		
<del>2:20 - 2:45</del>	NASA ESE Strategic Views	Bob Schiffer
2:45- 3:00	ESE UAV Science Mission Demonstration Program	Cheryl Yuhas
3:00 - 3:15	Break	
<b>Potential Science Roles</b>		
<del>3:15 - 3:30</del>	Stratosphere Chemistry	Estelle Condon
3:30- 3:45	Radiation science/CRYSTAL	Vic Delnore
3:45- 4:00	Applications	Ernie Paylor
<b>Real World Experience</b>		
<del>4:00 - 4:15</del>	DOE/ARM	Will Bolton
<b>Workshop Summary</b>		
<del>4:15 - 4:45</del>	Workshop Summary	Steve Wegener

~~Workshop Summary~~

We'll start off with Bob Schiffer talking about the high level NASA views. Cheryl Yuhas will then talk about the UAV science mission demonstration program within Code Y. I want to talk about some of the potential science roles. Estelle Condon will give us a flavor of what some of the stratospheric chemistry issues are. Vic Delnore will talk about radiation science. Ernie Paylor will talk about applications as seen from the Headquarters perspective in Code Y. Will Bolton will talk to some of the real world experience from the recent DOE [Department of Energy] ARM [Atmospheric Radiation Measurement] experiences.

# Discussion Workshop Summary



- Discussion
- Questionnaire
  - Perceived near term UAV science roles
  - Barriers to UAV Science Missions
  - Other considerations
- Event Evaluation

Science Workshop

Then we'll go into the summary activities. We'll pass around a questionnaire, while we're doing discussion. I'd like to get some feedback from you as to what you might see as perceived UAV science roles—stuff that we might be able to be doing in the next couple of years. Interest that you may have in the UAV NASA Research Announcement that is coming out soon.

# Speakers Notes



The workshops at the ERAST event will be recorded, transcribed, and converted into a conference publication (CP).

**Please**

- Identify yourself before you speak, if only to say "member of the audience."
- Speak clearly and distinctly.
- When you use acronyms, please state what they stand for, for example: ERAST (Environmental Research Aircraft and Sensor Technology).
- When you refer to people, please give their full names
- When you refer to aircraft or special equipment, please give their full designations.
- Please also provide a copy of any presentation materials .

Science Workshop

I'd like to also hear what you from the science community might perceive of as the barriers to doing UAV science, and then certainly any other considerations that you might have in terms of insurance issues, communications issues, data issues—those types of things that you might want to get some feedback from the speakers on.

I'd like to introduce our first speaker, Dr. Robert Schiffer, the Deputy Director of the Science Division, acting in that position right now at NASA Headquarters. Bob has been a previous Chief of the Atmospheric Science Branch at Headquarters. Been with NASA for 27 years. He's an atmospheric physicist and also an aeronautical engineer.



## **NASA Earth Science Enterprise (ESE)**

**presentation to the ERAST Science Workshop  
14 October 1999**

**Robert A. Schiffer  
ESE Research Division  
NASA Headquarters**

Dr. Robert Schiffer: I'd like to talk to you about some of the motivation in the Office of Earth Science at NASA and point out that essentially we are a science-driven office. Our science drives the applications program. It drives the technology development. It drives the selection of flight missions, and essentially it has a central role in virtually every aspect of the program.



### ***Earth Science Enterprise Mission***

**"...to develop understanding of the total Earth system, and the effects of natural and human-induced changes on the global environment."**

#### **GOALS**

- **Expand scientific knowledge of the Earth system using NASA's unique capabilities from the vantage points of space, aircraft, and in situ platforms**
- **Disseminate information about the Earth system**
- **Enable the productive use of the Earth Science Enterprise science and technology in the public and private sectors**

Essentially, the mission of the Office of Earth Science is developing an understanding of the total Earth system, the effects of natural and man-made influences. We're a part in NASA of the U.S. Global Change Research Program, which is a multi-agency national program directed at studying long-term changes in the global environment. We're one of the key players. Our central role is primarily in terms of observations, data management, and basic studies of scientific phenomena. The goals of our program are expanding the knowledge base of the various processes that we're considering, using the unique vantage point of space, aircraft, *in situ* measurements, ground base measurements. The selection of what type of measurements one would look to is really problem dependent. There are some aspects of global change that require monitoring, which kind of lean toward the space global observing capability. There are other aspects of the problem that really focus on understanding processes where you have totally different requirements in terms of space and time sampling of the phenomena, and more appropriately need to be attacked with focused *in situ* and airborne programs. We also were responsible for ensuring archiving and dissemination of data and research results. And to ensure that, there's a translation of the findings and technology into the public sector for use by the citizenry.

One of the basic philosophies, I think, underlying our program is recognition that national policy really depends, in many cases, on a sound scientific basis. And NASA, not being a regulatory agency, serves as an R&D agency. We have a particular responsibility to promote the basic understanding of the scientific aspects of the various problems that we're dealing with.

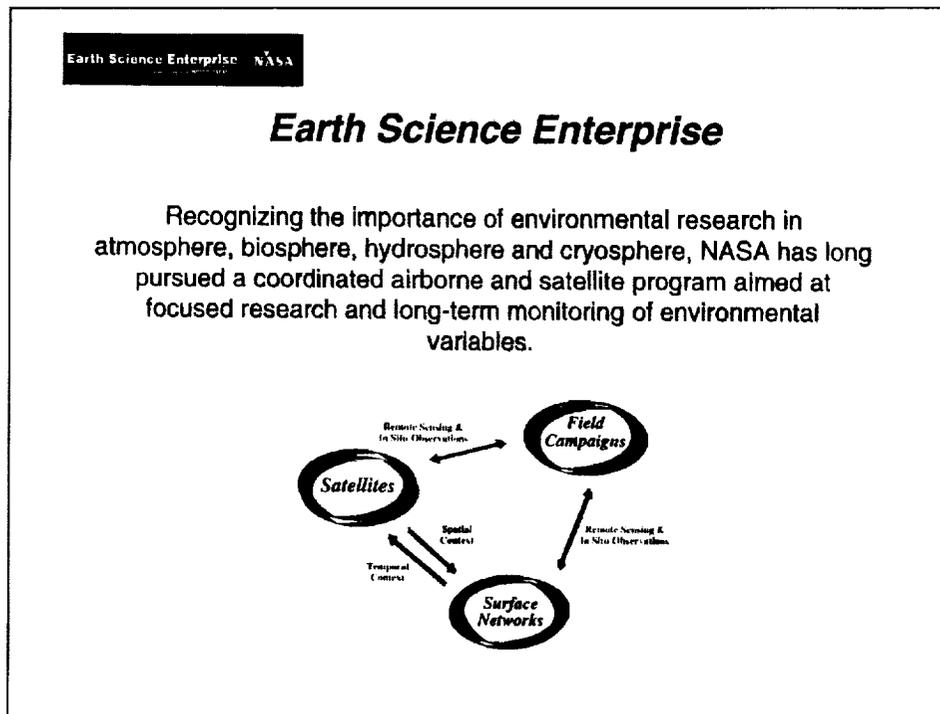


### ***ESE Program Elements***

- **Research:** Basic Earth science R&A and related EOS and other mission science teams, the airborne science program, UAV science program, and the interdisciplinary research investigations.
- **Applications, Commercialization and Education:** Application research in geodynamics, geology, natural hazards, resource vulnerability assessment, related EOS science and mission science teams, Education and Outreach, GLOBE, and the Commercial Remote Sensing Program
- **Advanced Technology:** supports development of key technologies to enable our future science missions. Includes NMP, Instrument Incubator, HPCC, Advanced Technology initiative, Advanced Info System Technology
- **Mission Implementation and Operations:** develops and operates the EOS flight missions and EOS follow-on missions, a comprehensive Data & Information System, and Earth Probes

The way we're structured in Earth Science, the science program itself is vested primarily in the Research Division, with the exception of the geodynamics and geology solid earth programs which, for one reason or another, are in the Applications Division. On the other hand, I think it's safe to say there's a very close working relationship with both organizations. That's just an artifact of the way we're structured. There's also an activity on advanced technology development and mission implementation.

And, again, I want to reiterate that all of these are driven by the science and applications requirements of the program.



Essentially, if you look at the three foci of the program, NASA's primary role in this area is—since we're in the space biz, and with a primary U.S. agency for our research—satellite based research. We have a special responsibility there. On the other hand, we have major activities associated with understanding processes that involve field campaigns. Here we see the important role of airborne systems, both manned and perhaps in the future unmanned systems, for a variety of functions—the obvious one being for providing verification, validation and ground truthing for satellite measurements. It's naive to think that satellites alone can do the job. They have to be benchmarked to *in situ* and airborne measurements. Of course, there is a number of surface networks that are involved in the program, again, from NASA's point of view primarily for validation and to provide a sense of certain variables that can't effectively be measured by remote sensing. There are certain fluxes that you can model but you can't directly sense, and you've got to go to *in situ* network systems.

I'm going to go through some of the key questions that are driving our program. We've recently produced a science implementation plan which is now undergoing external review by the science community that really lays out our entire science program over the next decade, primarily looking to the era beyond the first suite of Earth Observing System (EOS) platforms which are about to be launched. We've essentially described the program in terms of key scientific questions which really motivate the structure of the program. In contrast to some of the other science enterprises within NASA, which may be justified and may derive primarily from discovery and understanding, the Earth Science program has a human context to it, in that we have to be responsive to contemporary scientific issues that have social and economic consequences. Probably the two that have had the most publicity in recent years are ozone depletion and global warming. But we're seeing ourselves being held to a standard by the Office of Management and Budget and by the Congress. There's an insistence that our research program

eventually has a practical payoff for the country. So we've cast our program in terms of the number of key scientific questions, and I'm going to refer to five of them here that really form the basis for our long-term science planning.

**HOW IS THE EARTH CHANGING  
AND WHAT ARE THE CONSEQUENCES FOR HUMAN CIVILIZATION?**

**1. WILL THE EARTH PROVIDE FOOD, CLEAN WATER AND RENEWABLE RESOURCES TO SUPPORT HUMAN CIVILIZATION IN THE FUTURE, AND HOW WILL HUMAN ACTIONS AFFECT THIS ABILITY?**

- How do ecosystems respond to and affect global environmental change?
- How are land cover and land use changing? What are the causes and consequences?
- What is the role of ecosystems in the global carbon cycle and might this role change in the future?

**2. WILL THE EARTH PROVIDE ADEQUATE WATER RESOURCES FOR HUMAN CIVILIZATION IN THE FUTURE?**

- Is the cycling of water through the atmosphere accelerating?
- To what extent are variations in local weather, precipitation and water resources related to global climate change?
- How can the integrated effect of fast atmospheric, land and ocean surface processes be accurately included in large-scale climate models?

The first one is: Will the earth provide food, clean water, renewable resources to support human civilization in the future, and how will human actions affect this ability? And this is a profound question. There is a number of subsidiary questions that go with it.

The second is: Will the earth provide adequate water resources for human civilizations in the future? This is a key issue. And I'm sure in the State of California the issue of water resource management is a major concern.

**3. CAN WE EXPECT CLIMATE CHANGES OF CONSEQUENCE IN THE NEXT DECADES AND CENTURY, AND WHAT WILL BE THE CAUSES FOR SUCH CHANGES?**

- Can current global climate variations be understood and predicted?
- Can observed global climate trends be attributed to specific factors?
- Can change in polar ice sheets seriously affect global sea level?

**4. HOW DO EMISSIONS FROM HUMAN ACTIVITIES AFFECT THE ATMOSPHERE AND THE QUALITY OF AIR?**

- How will stratospheric ozone respond to reduction in atmospheric abundances of ozone-destroying industrial chemicals?
- How does the chemistry of atmospheric trace constituents respond to and affect climate?
- What are the effects of regional pollution on the global atmosphere and the effects of chemical changes on regional air quality?

The third is: Can we expect climate changes of consequence in the next decade and century, and what will be the causes of such changes? What's the role of man-induced influences as opposed to natural phenomena? There is a number of subsidiary questions with that.

The fourth is: How do emissions from human activities affect the atmosphere and the quality of air and life?

**5. HOW CAN KNOWLEDGE OF THE EARTH'S MOTIONS BE USED TO PROVIDE WARNING OF EARTHQUAKES, VOLCANIC ERUPTIONS AND OTHER NATURAL HAZARDS?**

- What are the motions of the Earth and the Earth's interior, and what information can be inferred about Earth's internal processes?
- How is the Earth's surface being transformed and how can such information be used to predict future changes?

And, finally, the fifth one is: How can knowledge of the earth's motions be used to provide warning of earthquakes, volcanic eruptions and other natural hazards?

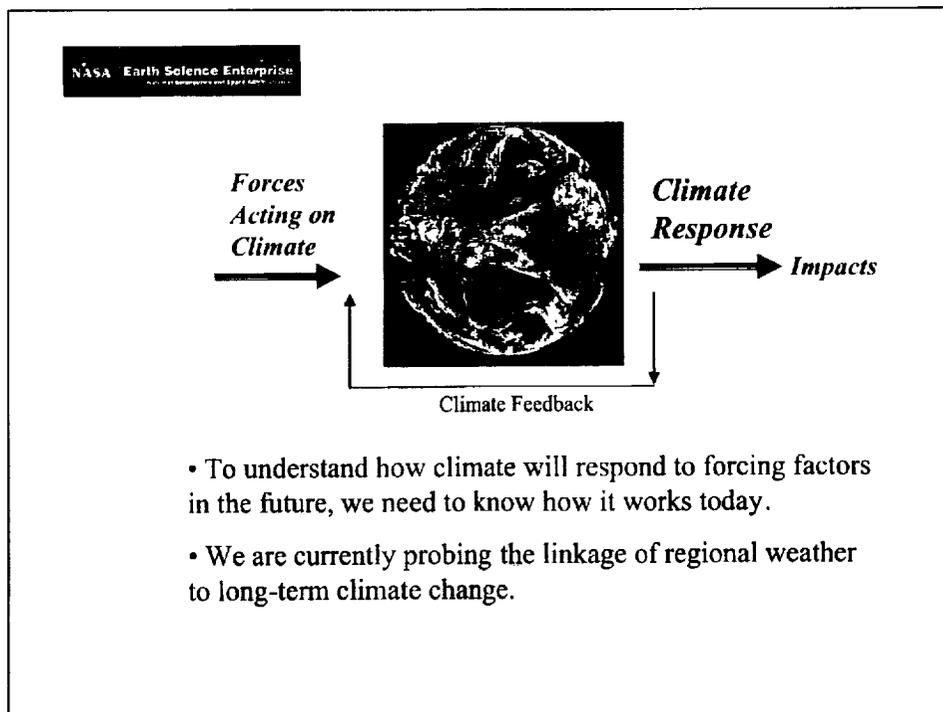
These five questions really constitute the main justification of our new science implementation plan. We're moving from the era of big satellites to smaller, dedicated, more focused, quicker, better, cheaper paradigm-types of missions, and we have the ability to be more responsive to changing scientific priorities. And I should point out that these questions really underpin the entire planning process for our program.

NASA Earth Science Enterprise

**Example of a key scientific issue:**

**GLOBAL CLIMATE SYSTEM FORCING  
& RESPONSE**

I've selected one issue to dwell on for really most of my time. I thought that I'd use this as an example of how the process proceeds for how requirements are established, how you dissect an issue into its components that essentially lead to insight into what you need to do in terms of what kind of measurements to make, what kind of models you need, and what are the consequences of this. So I'd like to talk to the global climate issue.



It's convenient to look at one approach to understanding climate by looking at the forces acting on climate, the forcing agents, and look at climate response and feedback. Here our goal is to understand how climate responds to these different forces and how the processes work, what are the feedbacks, and is there a prospect—or to what degree is there a prospect—of developing the liable predictive capability. We're also looking at the linkages of weather phenomena to long-term climate change. It's somewhat simplistic—and I've seen this referred to many times—to describe climate as the integral of weather or weather being climate noise. It's not quite that simple. It's much more complicated than that and, in a sense, does a disservice to the science of climatology.



Climate Forcing

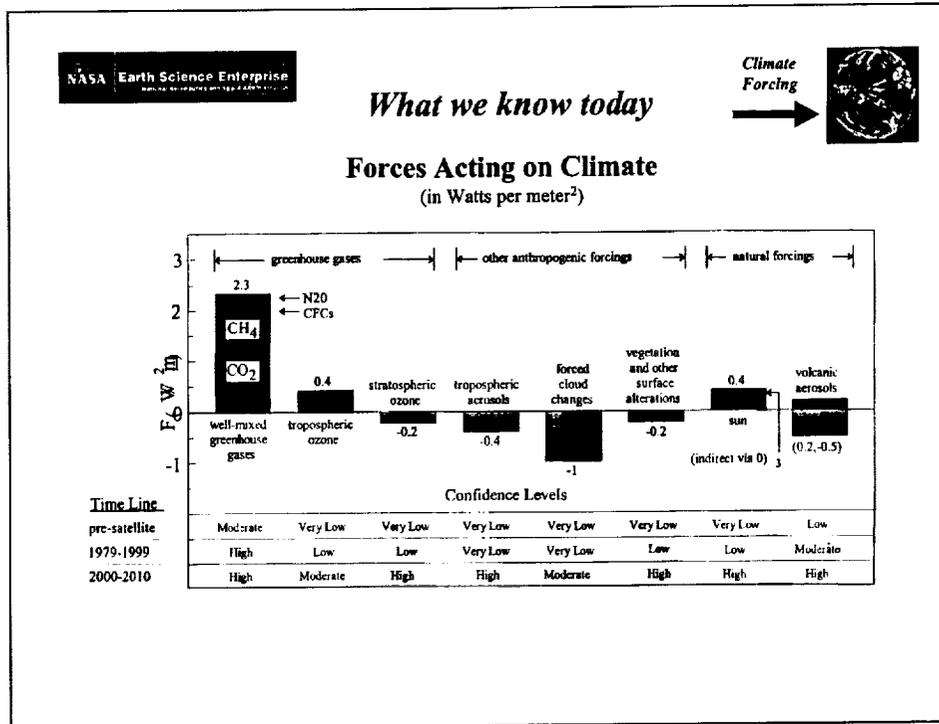


### *What do we know about climate forcing?*

- Human-induced forces acting on climate
  - Concentrations of carbon dioxide, methane, nitrous oxide, and other trace gases are rising as a result of human activities
  - Carbon dioxide has nearly twice the impact on warming of the atmosphere as all other gases combined
  - Lower atmosphere aerosols associated with air pollution have significant local cooling effects that can counteract some of expected warming
- Natural forces acting on climate
  - Variations in stratospheric aerosols associated with large volcanic eruptions (esp. Mt. Pinatubo in 1991) have measurable surface cooling effects on climate system
  - Changes in the Sun's output and the Earth's orbital position lead to variability in solar energy reaching the Earth's atmosphere

If we look at climate forcing—I'd like to kind of break this up and see where we are in terms of what we know, what we expect, what is it that we don't know, and where do we expect to be. In terms of what we know about climate forcing—we have some insight into the human dimension of forcing. We know that man, through his actions, is dumping great quantities of radiatively active gases into the atmosphere. We know that carbon dioxide has twice the impact on climate of all the other gases combined. On the other hand, on a molecule-by-molecule basis, other gases—other radiatively active gases—may be more efficient in terms of their impact on a radiative balance. But there's a lot more carbon dioxide. On the other hand, water vapor is, in fact, the key greenhouse gas. And that's mainly associated with natural phenomena.

In terms of natural forces on climate, we see that there's a major effect due to natural phenomena such as volcanic aerosols. The Pinatubo volcano that went off a number of years ago had a marked impact on tending to mask the greenhouse signal in the atmosphere by acting in the opposite direction. The effect of stratospheric aerosols tends to counter, in sign and direction, the effects of increasing greenhouse gases. Then, of course, we have the primary forcing agent on the climate of the Sun. There's no feedback to the Sun that we can imagine, and it's important to maintain a monitoring program since sensitivity studies of models show that prolonged changes in solar output can have a potentially significant effect on climate.



This is an interesting cartoon that's been used many times. This comes from the IPCC report—the Intergovernmental Panel on Climate Change. It attempts to show the proportion of the contribution of different sources of forcing agents acting on climate. What it doesn't show, unfortunately, is the error bars associated with each of these forcing agents, which I think would be more illustrative. But of the uncertainties, the fact that if you superimposed uncertainties on this, I would think that the cloud feedback alone could be a major source of uncertainty that could mask much else of what we think to be the net forcer.

*What don't we know about climate forcing?*

- Future emissions and atmospheric concentrations of carbon & other greenhouse gases
- Direction of feedback due to carbon absorption by land surface and oceans
- Rate of excess heat storage in the oceans
- Feedback loop between atmospheric chemistry and climate
- Impact of changes in aerosol distribution from industrial activity & biomass burning on how the atmosphere responds to solar energy
- Reflective properties of different types of aerosol particles and their impact on how the atmosphere responds to solar energy
- Impact of Sun's variability on climate over multi-decadal time scales

Okay. What don't we know about climate forcing? Of course, there are many models of what future emissions and concentrations of carbon and other greenhouse gases are. There are different models of projecting based on fuel consumption and other uses. We don't really understand fully the feedback due to carbon absorption by the land surface. In fact, within the U.S. Global Change Research Program is a major study developing on trying to close the carbon budget. That's a formidable task. We don't know accurately the rate of excess heat storage in the ocean. There is a number of feedback loops between chemistry and climate that we don't understand. These are significant factors that we're going to have to deal with if we're ever to achieve reliable understanding and predictive capability.



***What we will learn about climate forcing over the next 5-10 years?***

- Solid understanding of the forces acting on climate and their comparative strengths

	<i>Confidence level</i>	
	<u>Current</u>	<u>2010</u>
- Greenhouse gases*	High	High
- Tropospheric ozone	Low	Moderate
- Stratospheric ozone	Low	High
- Tropospheric aerosols	Very Low	High
- Forced cloud changes	Very Low	Moderate
- Vegetation / surface	Low	High
- Sun's output	Low	High
- Volcanic aerosols	Moderate	High

\* Considerable uncertainty exists in forecasts of future carbon dioxide & methane

Here's what we expect to do over the next five to ten years. We've given an assessment of where we are in terms of our confidence level and being able to determine the effects of a number of these parameters. We expect that in the next five to ten years we should make some significant improvements. Many of these are amenable to investigation with airborne platforms. We're not wedded at the hip to satellites, although they are in essence the major player in our program. We have a very strong dependence on airborne and *in situ* systems. But this is kind of an assessment of where we expect to be with the research program that's in place over the next five to ten years.



### *What do we know about climate response?*

- In the last 100 years
  - Global mean surface temperature has risen by 0.5C
  - World glaciers have retreated drastically
  - Global mean sea level has risen by 20 cm
- Greenland ice sheet is thinning on East slope but growing on the west slope
- Larsen Ice Shelf in Antarctica has lost 10,000 km<sup>2</sup> and its margin has retreated by up to 50 km in the last 50 years
- Growing season appears to have lengthened in much of the mid-latitude northern hemisphere (1/2 day/year over 30 years)
- Frequency of extreme rainfall events (> 2 in./day) appears to have increased in recent years, although this has not yet been directly tied to climate change
- Understand basic mechanics of El Niño and La Niña, and predictable relationships to rainfall in several regions of the world (e. g. West coast of the USA).

Where are we with the climate response? We have fairly reliable records going back over the last 100 years or so that give us a good indication of what we think the temperature rise has been. We've seen evidence of the retreat of glaciers. There's been some modest increase in sea level. There's thinning of the Greenland ice sheet in some areas, but there's thickening in other areas. So that jury is still out. The ice shelf in Antarctica is diminishing. Recently there have been several papers published that have essentially questioned whether the effects of the Antarctic ice sheet are due to greenhouse warming, as opposed to a process that's been going on for thousands of years. And, again, the jury's out on that. We do see evidence that there have been increases in the growing season. A number of papers have been written on that issue. We're gathering statistics on changes in rainfall—an extremely important parameter. We're improving our understanding of the basic mechanics of El Niño and La Niña, and developing a more reliable predictive capability, although there are some serious questions still with understanding the basic trigger mechanisms. Once we see the signal, we're making progress on the next step of predicting its evolution. But we have not come to grips with understanding the basic fundamental triggering mechanism.



***What don't we know about climate response?***

- How does increasing temperature affect the amount of water in the atmosphere and the formation of clouds? How will this affect rainfall patterns, and dependent activities like agriculture?
- Are changes in local weather, precipitation and water resource related to global climate change?
- Could climate change result in a “runaway greenhouse effect”, analogous to Venus?
- How might ocean circulation change? e.g., could the Gulf Stream disappear, leaving Europe much colder?
- How will the mass of ice at high latitudes change, and how will these changes feed back on the climate system?
- How will changes in climate affect the balance between emission and uptake of carbon dioxide and methane by living organisms?

What is it we don't know about climate response? Again, this is primarily associated with our poor understanding of many of the feedback mechanisms. What's going to be the effect on clouds in a changing climate? We've amassed over the last 15 years very comprehensive climatologies of global cloudiness, primarily from satellite measurements, and we've begun to assess the radiative impact of clouds. But we have no idea as to what the cloudiness distributions would be in a different climate state. As climate would evolve, how would the global cloudiness change? Would there be more cirrus? Would there be more stratoform clouds? These are fundamental questions to which we're devoting a considerable amount of research effort.

There's a question of, could climate change result in a runaway greenhouse effect analogous to what happened on Venus? At this point, that's really just a speculative hypothesis. There's no evidence that that's actually happening. This concern about ocean circulation is very significant. The Gulf Stream—the thermohaline circulation in the Atlantic—is extremely important for modulating weather patterns in the Northern Hemisphere, particularly in the north Atlantic and in Europe. If there's a disruption, for example, in the Gulf Stream, associated with perhaps changes in thermohaline circulation, this could have absolutely devastating effects to the climates in Northern Europe. If you just look at the latitude of most of the countries in Northern Europe, they are the equivalent of northern Canada and Labrador. So the benign climates that they experience are really influenced strongly by the ocean circulation in the Atlantic, and disruptions in that could be devastating. I think there's beginning an awareness and concern about this amongst the European scientists. Of course, there are questions about changing the effect of diminishing ice due to global warming, for example. If ice is having a negative feedback on climate—if the ice diminishes, if the sea ice were to retreat—then it essentially tends to exacerbate the problem. I mentioned before the carbon dioxide issue.



***What we will learn about climate response the over next 5-10 years***

- Solid understanding of the mechanics of climate responses

	<i>Confidence Level</i>	
	<u>Current</u>	<u>2010</u>
- Severe storms	Low	Moderate
- Droughts and floods	Low	Moderate
- El Nino frequency	Low	Moderate
- Fresh water availability	Low	High
- Ecosystem changes	Moderate	High
- Ocean circulation	Moderate	High
- Sea level change	Moderate	High
- Ice sheet mass	Low	Moderate

You recognize the phenomena that are listed on the left [of the slide being shown]. There's something in the newspaper virtually every day about one or the other of them. And unfortunately at this point we have a limited scientific understanding of the basic mechanics of how these phenomena are driven. And our program is geared in response to these fundamental questions that I described in the beginning, We're focusing on trying to make some serious headway into improving our understanding.

***Airborne Science in ESE***

- Airborne science supports:
  - the Research Division's major field campaigns, which can include several aircraft, numerous agencies and /or international partners, and take place worldwide for a period of weeks to months;
  - Earth Science satellite calibration and validation experiments;
  - Earth applications and commercialization programs;
  - individual Principal Investigator flight requests;
  - selected interagency programs, either on a cooperative or cost recovery basis;
  - a data facility at the Ames Research Center that processes data and maintains/calibrates facility airborne sensors;
  - response to federally declared emergencies (e.g. wildfires, floods, earthquakes), and provides emergency management officials with rapid response images through the data facility.

Finally, I remind you that there are essentially three thrusts that our office depends on airborne systems for. The fundamental two in the past have been the validation of intercomparison of satellite data—ground truthing of satellite data, and the incorporation of airborne systems in studying climate and chemistry processes. There's a long history of the use of airborne systems, particularly in atmospheric chemistry. I expect this to increase somewhat in the future. The third area, of course, is the use of airborne systems for disaster surveillance. As long as I've been at NASA Headquarters, there have always been requests coming from local governments, from states, from different regions for NASA airborne coverage to consider their response to natural disasters.

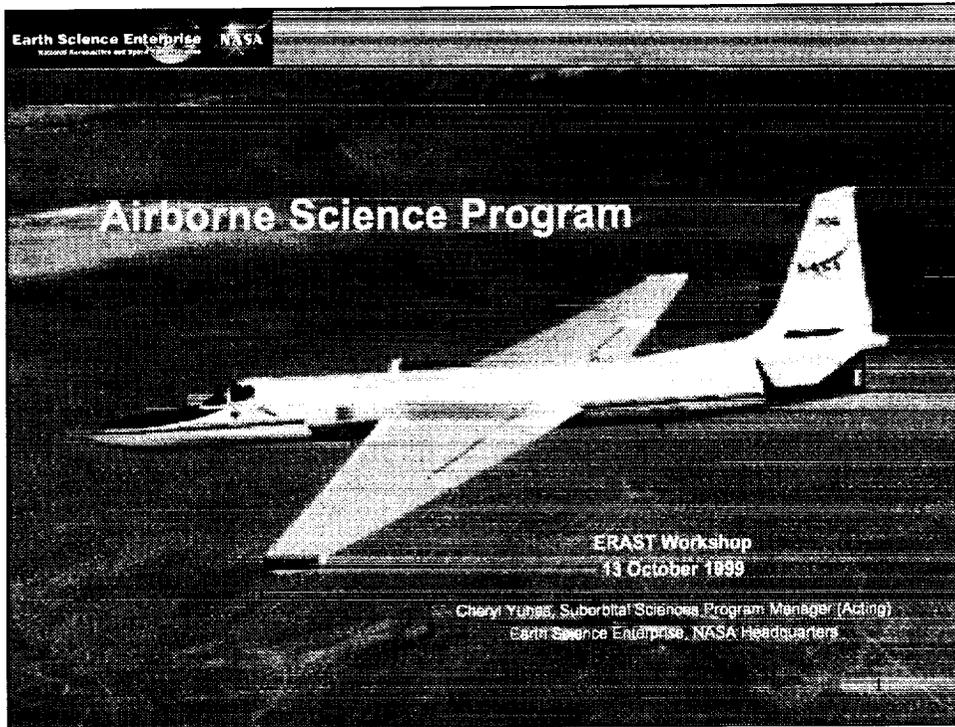


### ***ESE Airborne Science Tomorrow***

- NASA is actively pursuing a transition from piloted to unpiloted aircraft (UAVs), however:
  - the transition will not occur overnight;
  - science must not be compromised;
  - NASA and its partner agencies will leverage off development programs in the DoD, where possible (e.g. Global Hawk);
  - NASA will evaluate available UAV platforms, such as those operated by CIRPAS;
  - NASA will evaluate quasi-UAV platforms, such as Burt Rutan's PROTEUS, for suitability to its missions;
  - NASA's ERAST program continues to contribute to UAV platform and instrument developments.
- NASA will release an NRA solicitation for UAV-based science, that will allow investigators to match their science requirements to the UAV capability.

There are several talks that are also scheduled a little later. Cheryl is going to discuss what this means in terms of the airborne sciences program at NASA, which is also managed out of our office and the Research Division. Estelle Condon is going to talk about the science associated with the chemistry program, and Ernie Paylor will talk about the applications program. So in one short session like this we're going to try to give you not enough to choke on, but at least enough to stimulate interest.

Steve Wegener: Now Cheryl's going to talk about the Airborne Program. Cheryl is the Suborbital Sciences Program Manager, again acting, in the Office of Earth Science at NASA Headquarters. Cheryl manages the NASA remote sensing airborne assets. That includes aircraft and instrument payloads that support field campaigns and the Cal/Val experiments—or Cal/Val activities for Earth Science research and analysis programs, the R&A Program, EOS, and earth system science Pathfinder missions. The Airborne Science Program is also being extended to encompass new technology platforms like UAVs, as well as other suborbital platforms.



Cheryl Yuhas: What I thought I'd do is talk a little bit about the Airborne Science Program as we're operating it now. Because it will give you an idea of how we want to use UAVs in the context of the Earth Science Program. So I'll go through the first charts rather quickly and spend more time with the UAVs later on.

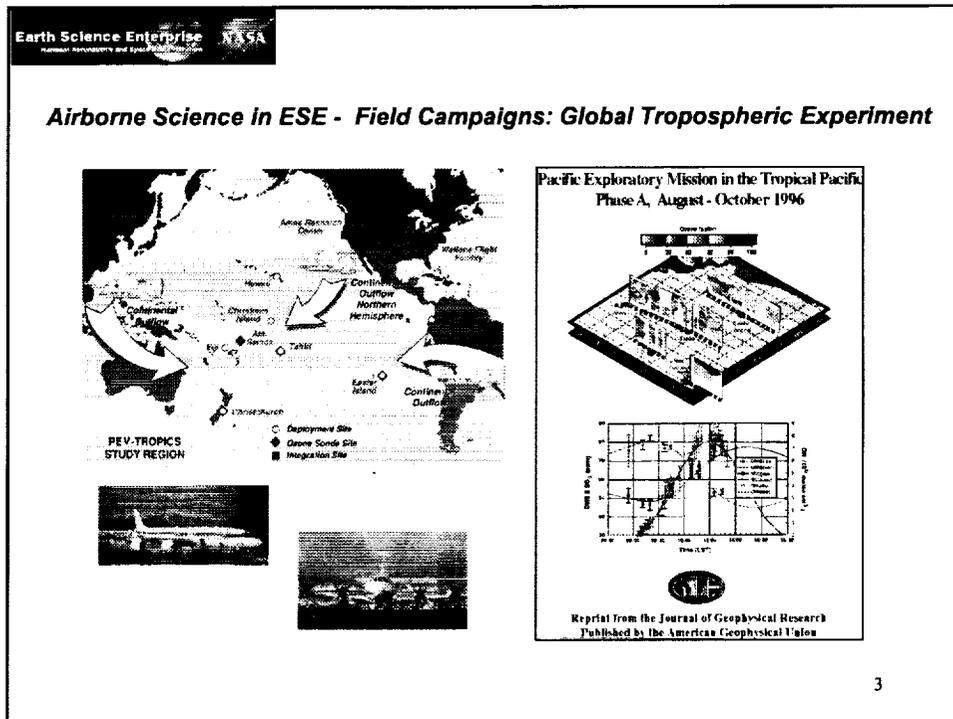
Earth Science Enterprise NASA

## ***Airborne Science in ESE***

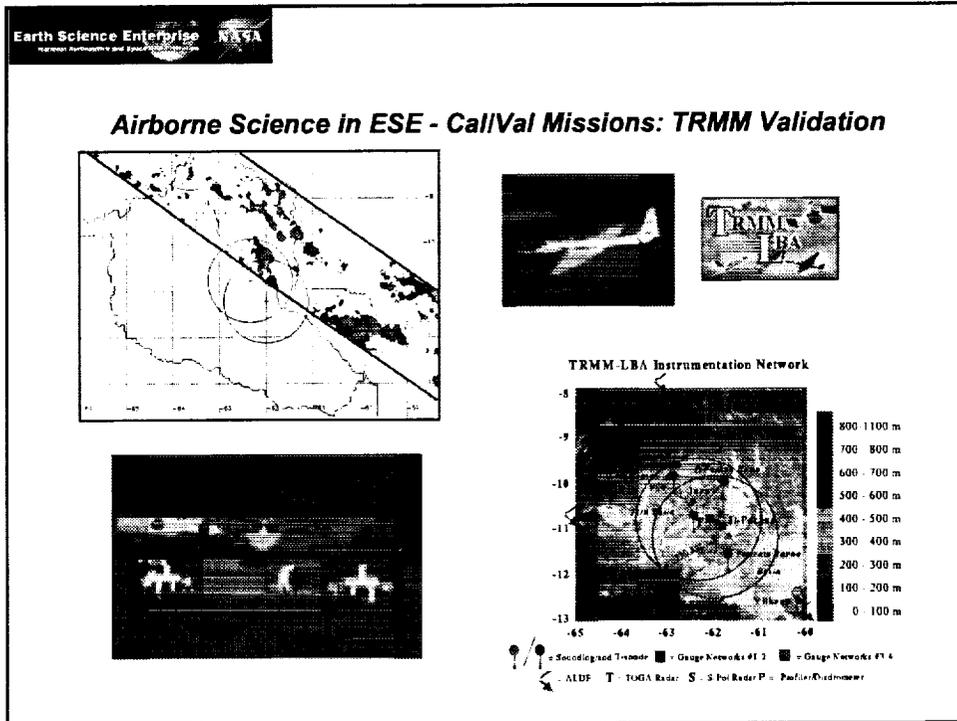
- Airborne science supports:
  - the Research Division's major field campaigns, which can include several aircraft, numerous agencies and /or international partners, and take place worldwide for a period of weeks to months;
  - Earth Science satellite calibration and validation experiments;
  - Earth applications and commercialization programs;
  - individual Principal Investigator flight requests;
  - selected interagency programs, either on a cooperative or cost recovery basis;
  - a data facility at the Ames Research Center that processes data and maintains/calibrates facility airborne sensors.

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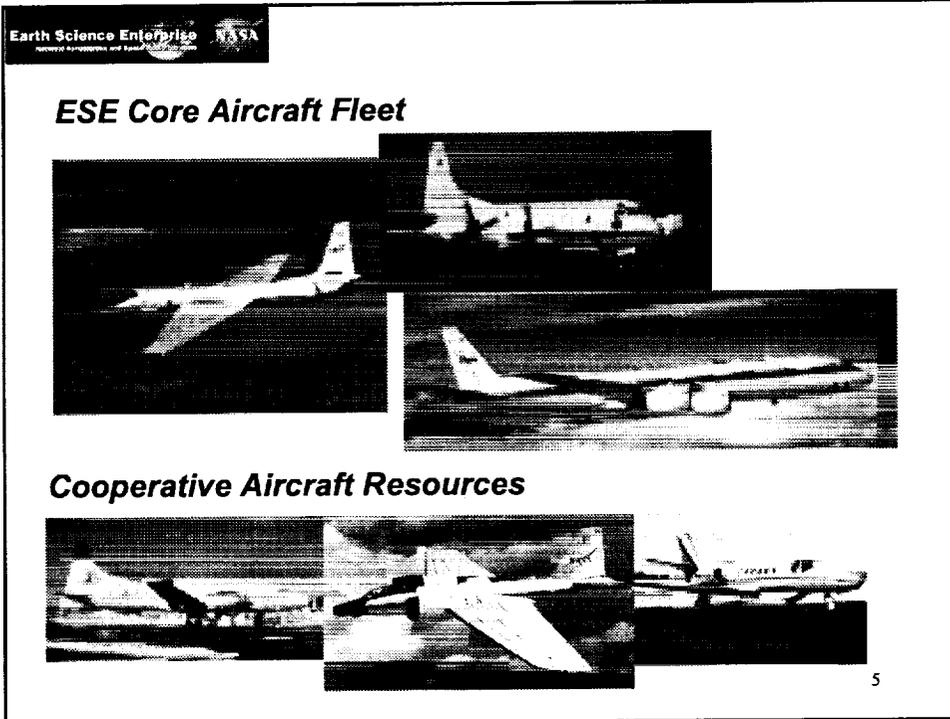
Basically, airborne science is an essential part of the Earth Science Program because we have satellites but we need the aircraft for anchoring the satellite measurements *in situ* and for focus process studies, and then for the individual investigators who need the special perspectives available from lower in the atmosphere as compared with what you get from satellites.



This is an example of a focused aircraft campaign—the atmospheric chemistry in the troposphere. And you can see that we usually use multiple aircraft. It shows here the P3-B out of Wallops Island and the DC-8 out of Dryden. It also shows that when we're finally done, we've learned something new about the troposphere. That ends up with the special report in the *Journal of Geophysical Research* that I think was the source of that slide.



This is an example of the Cal/Val (calibration and validation) missions that are so essential to the success of a satellite mission. This is the Tropical Rainfall Measuring Mission (TRMM) satellite. It took the first rain-measuring radar into space—the first one ever on orbit. We needed to have the aircraft campaigns in order to understand and validate that the algorithms that we were using to retrieve the rainfall from the space-borne radar were, in fact, working correctly as we thought. We put a lot of things together to make this work. You see the satellite path where we take the aircraft below the satellite track. That's in the upper left-hand corner (see accompanying illustration). You have in the lower left-hand corner the *in situ* platform for cloud microphysics. As shown in the upper right-hand corner, we used the ER-2 to take airborne radar to simulate the satellite. Then we had an extensive ground campaign with rain radars and rain gauges on the surface. All of these together make the satellite mission mean something to us so we can learn something new. That's why the aircraft campaigns and the aircraft missions within the Earth Science Program are so essential. Without them we would not know for sure what our satellites are telling us.



The next chart is a sample of the sort of aircraft we are using today. On the upper section of the chart we have the core aircraft that the Earth Science Division supports permanently. We have two ER-2's for the high altitude, the P3-B and the DC-8 for more hands-on, laboratory, low-to-medium-altitude-type facilities. And in the lower part of the graph you see some of the cooperative aircraft that we've used—the CV-580 from universities. We get aircraft from other organizations within NASA. This is the WB-57 that is stationed at Johnson Space Center. And in the far right is the DOE Citation, which provides an additional remote sensing platform for us. The point here is that we have the four core aircraft that we are using with a certain set of capabilities. When we need additional capabilities for a scientific mission that has been proposed, we go out to look for other people with other capabilities. In this case, we've been staying with the manned aircraft because that's really all we've had that have reliably performed for us in the past. We're looking forward to the UAVs. We feel that UAVs will bring us a very exciting new capability.

## Using ESE Airborne Resources

- ESE airborne resources assigned on annual basis:
  - requestors select aircraft based on capabilities, e.g. high-altitude;
  - actual use of aircraft are assigned based on the proposed science mission:
    - requests are approved if mission is part of a competitively-selected ESE grant, contract, mission science team, sensor development program, or cooperative program;
    - priorities are assigned by science requirements of the mission.

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The point of this chart really is that when we approve an airborne mission and assign it to one of the airborne platforms that we have, we base it on the science content, not on what the aircraft is. And that's really the key thing. We are a science-driven organization. And that's what drives our decisions.

## ESE's Strategy for UAVs

Directed Development  
1994-2003



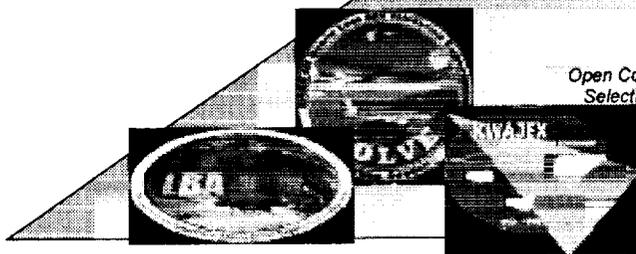
UAV-based Science  
Mission Development

Merged Airborne and  
UAV Suborbital Program  
2006-2010

Science-Driven  
Missions

Open Competition and Peer Review  
Selection based on scientific merit

Multiple platform choices  
• high/medium/low altitude  
• laboratory  
• uninhabited  
• other suborbital



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And this gives the strategy that we're looking for in UAVs. We saw right away that the UAVs can provide new and exciting opportunities for observation. This includes the ability to reach higher in the atmosphere because you're not having to expend your mass on the pilot and the life support needed. We also have the ability to do extended durations where we can observe diurnal processes. Then we also have the ability to send an aircraft into a situation that may be hazardous for a person, like nuclear accidents and things like that. So we see that there're a lot of new things that we can do with UAV platforms. The ERAST Program has been working to a set of requirements that we developed based on what we can do that is new, based on these unique capabilities that a UAV will bring to us.

Our long term goal is to have the UAV as simply another platform of choice within the airborne program. The kinds of missions that we just described, the kinds of questions that Bob just described and that Dr. Paylor will describe later for the applications themes—once we know what these things are, we choose the platform which is most appropriate for what we want to achieve. In many cases, we look forward to the UAV providing one of these new platforms. To get from where we are now where we're developing new platforms to that future where we simply develop a science campaign to answer a science question and use the most appropriate platform, we started with what I call a directed development. Essentially, that's something like the ERAST Program where we've developed these new aircraft we saw today, which I find very exciting and I look forward to seeing some work done with those—to what we're calling now a UAV science mission development. This is where we're moving to now. We've seen that the platforms have developed. We've seen it here within ERAST. We see that there's development out in the military world and in the commercial world. We believe now that we are in a position where these platforms can do something new and exciting for us. Let's see what science missions are really most appropriate for them.

That's what we think will continue beginning next year and probably through 2006. We're not sure whether it'll be a three- or a six-year development. It depends upon the progress that we see. Then basically, once we've done that science mission development, we've seen how it can work, we go back into our science driven missions and UAVs are now part of the core platforms for us.

## ***UAV-Based Science Demonstration NRA***

- ESE will release an NRA for UAV-based airborne science missions, draft for comment in October 99, competition in early CY2000, and selection/award by summer 2000.
  - Demonstrate that valid science missions, that take advantage of their unique capabilities, may be conducted from UAV platforms;
  - PI-mode, in which the PI proposes to one of the ESE questions and selects the UAV platform, ANY UAV MAY BE PROPOSED;
  - NASA facilitators to assist PI in identifying UAV operational constraints and capabilities;
  - 2-3 awards, totaling \$3-5M/year for 3 years (follow-on NRA under consideration);
  - strawman schedule assumes Year 1 Mission Planning; Year 2 Flight; Year 3 Analysis & Results.

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How are we going to do this science mission development—the directed development? We're going to release a NASA research announcement later this year. We hope to do a draft for comment next month with an actual release out very early next year. The objective of this is to demonstrate that valid science missions that take advantage of the unique capabilities of UAV can be performed, and that when you're done you can take the data—you can analyze it and you can publish it in a reference journal. This is valid stuff that we can do. And UAVs bring a unique capability to it. The way we're going to do it is what we call PI mode, or principal investigator mode—in which the principal investigator has complete and full control over what is going to be done, womb to tomb. You start out looking at one of the science questions that Bob just described or one of the applications focus teams that Dr. Paylor will describe later, propose to one of those themes—any one of them—and select your own UAV platform. It can be any platform that is out there with demonstrated capabilities. That's key to this. It's open competition to a peer review. We know that a lot of principal investigators may not be as thoroughly familiar as some who have been following the UAV development. And so we're going to provide a facilitator-type arrangement, sort of like a library or a reference arrangement for people to call and get help on some of the questions that have already come up this morning, such as insurance, and the regulations, and the restricted air space. That will help the potential proposer understand what all these issues are and what must be done in order to obtain a good science mission.

Now to the bottom line. We're expecting a budget of \$3 to \$5 million a year for these missions. We hope to make two to three awards. We'll look at it as a three-year mission with a strawman schedule of where you do your mission planning and any kind of development and integration in the first year, go into your flight mission the following year, and in the third year do your analysis and publish your results. This is the strawman schedule. But depending upon the UAV, upon the mission, upon the instruments that you would use, you would propose whatever you feel would be most appropriate to achieve your goal.

## **UAV-Based Science Demonstration NRA**

- **Facilitators**

Gary Shelton  
NASA/DFRC  
661-258-2919

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CIRPAS

831-384-2776

hjonsson@nps.navy.mil

David Pierce

NASA/GSFC/WFF

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- act as library reference:

- maintain list of UAV vendors, provide points of contact;
- assist in identifying UAV-related concerns/issues such as operational and regulatory constraints, liability issues.

- prohibited from proposing to NRA:

- cannot assist in proposal development, exchange information provided by proposers, or provide advice on science content.

NRA Release will be announced on the Earth Science Enterprise home page:  
<http://www.earth.nasa.gov/>

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I mentioned the facilitators. What we have here are three people who have been working with the science community already in the airborne world. So they are familiar with the PIs. They are familiar with the problems and issues that you will be facing. We have Gary Shelton from the Airborne Science Office here at NASA-Dryden. We have Dr. Hafliði Jonsson from the CIRPAS [Center for Interdisciplinary Remotely Piloted Aircraft Studies]—the Office of Naval Research Group at the Naval Postgraduate School at Monterey, California. And we have David Pierce, who has been working with the sounding rocket and balloon program at the Wallops Flight Facility of the Goddard Space Flight Center and is also familiar with some of the smaller, more applications-oriented UAVs that have been developed. They're going to act as a library reference. And one important thing—that when you deal with the facilitators that we want you all to understand is that they are prohibited proposing to the NRA themselves. They are there as a reference. They're not going to exchange data with everybody. They are there to provide advice to you and help to you.

And so that you can be aware of when this thing actually comes out, let me just say that we are working on the NRA now. It's in the concurrent cycle. As I said, we hope to release a draft for comment around the first of November. If you track the Earth Science home page, there will be an announcement on there when that release actually comes out, plus we will be sending out a general announcement to our regular mailing list. But this is also an easy way to keep track of what's going on.

## ***Future of Airborne Science in ESE***

- Comprehensive suborbital program to complement space-based observing programs
  - core flying laboratories to support process studies and cal/val activities with facility and PI instruments, for both remote sensing and in-situ;
  - unique observing capabilities provided through either core or cooperative platforms, including aircraft, UAV, balloons, rockets.

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Lastly, I just want to close by reminding you that what we're looking for is a comprehensive suborbital program that complements our satellite program within NASA. We want to provide core flying laboratories that provide very special capabilities for the Cal/Val and the focus missions that we pursue within Earth Science. We want to provide these unique observing capabilities through whichever means is possible. We look at a core platform and we look at bringing in the UAV as core cooperative platforms, but we want to make that capability available to all of our potential investigators.

Steve Wegener: The next speaker is Estelle Condon. Estelle is the Chief of the Earth Science Division at the Ames Research Center. Estelle has led several atmospheric science campaigns, including the airborne Antarctic ozone experiment, airborne Arctic stratospheric experiments one and two, airborne Southern Hemisphere ozone experiment/measurements for the assessment of effects of the stratospheric aircraft, which was really the first opportunity that we had within the airborne science community to explore the use of RPVs to make measurements above the ER-2. Estelle will talk about the potential UAV science roles in atmospheric chemistry.

# ERAST Open for Business

Atmospheric Chemistry

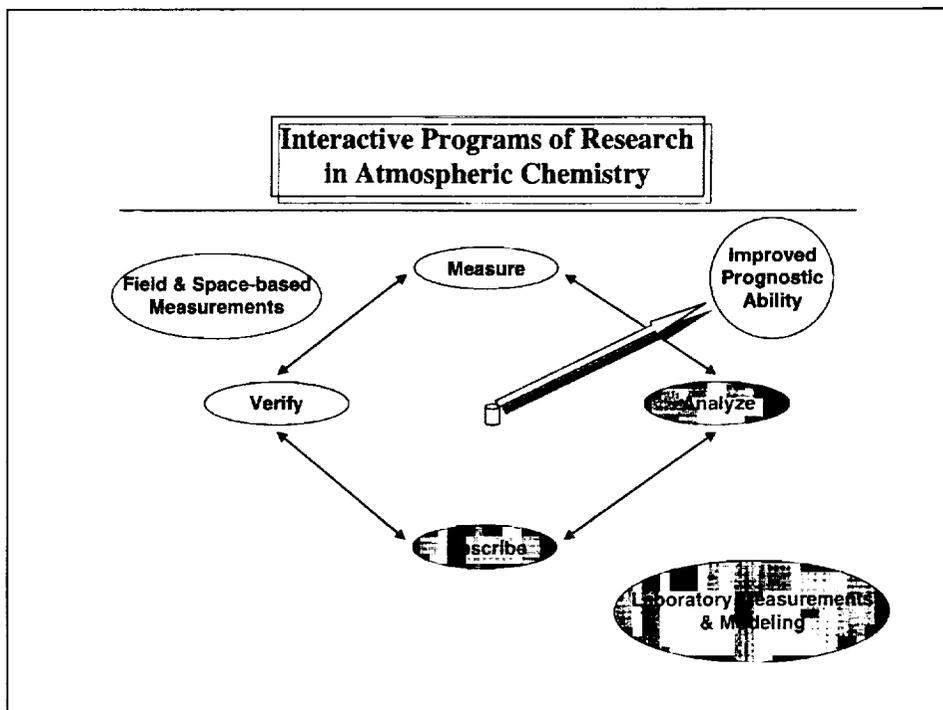
Estelle Condon, Chief  
Earth Science Division  
NASA Ames Research Center



Ames Research Center

October 13, 1999

Estelle Condon: I'm filling in for Dr. Mike Kurylo who couldn't be here today. And he is very sorry about that. But he had another commitment.



I'm going to give you a few minutes on the upper atmosphere research program primarily— atmospheric chemistry, the program that he manages. And then I'm going to give you a couple of ideas that I gleaned from some of my colleagues on potential UAV missions.

## ➤ Atmospheric Chemistry

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### ✧ Goal

- To develop a sufficient understanding of the physical, chemical and transport processes in the Earth's atmosphere (troposphere and stratosphere) with which to assess its susceptibility to change

### ✧ Planning

- Through advisory panels, in-house coordination, ad-hoc issue-focused workshops, science team meetings, conferences and symposia, and international assessment activities

### ✧ Implementation

- Through Upper Atmosphere Research Program (UARP) and the Tropospheric Chemistry Program (TCP)
  - Tropospheric and stratospheric field measurements
  - Atmospheric laboratory studies
  - Process modeling and analysis
  - Assessments and coordinations
- Theory, modeling, and data analysis [Atmospheric Chemistry Modeling and Analysis Program (ACMAP)]

The goal of this Atmospheric Chemistry Program at NASA is to really develop an understanding about the physical, chemical and dynamic processes in the earth's atmosphere, with the hope that we can assess change and the susceptibility to change. That's kind of the fundamental underlying goal of all of the research that Bob described a little earlier. The program is carried out and is planned through an enormous amount of input and interchange with the science community. There're all kinds of advisory panels and science team meetings and conferences as well as international assessments. This has all provided direct input into political processes that have, for example, resulted in the Montreal Protocol. So it's a very critical piece of this larger Earth Science program, because this one has had direct impact on national and international policy.

## ➤ Upper Atmosphere Research Program (UARP)

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### ✪ Congressionally Mandated Long-Range Scientific Research Program

- FY1976 NASA Authorization Act
- 1990 Clean Air Act Amendments

"develop and carry out a comprehensive program of research, technology, and monitoring of the phenomena of the upper atmosphere so as to provide for an understanding of and to maintain the chemical and physical integrity of the Earth's upper atmosphere"

This next slide is just to remind you that this particular piece of that Earth Science program is actually a congressionally mandated program. And it stems from a 1976 law passed by Congress. It was amended, I think, in the 1990 Clean Air Act. But NASA has a particular role, and that is to develop and carry out a comprehensive program of research technology and monitoring of the phenomena in the upper atmosphere so as to provide for an understanding and to maintain the chemical and physical integrity of the earth's upper atmosphere. So that's a fairly serious role that NASA has, directly mandated by Congress. And, incidentally, it's one of the very few congressional mandates that we have.

## ➤ UARP Long-Term Objectives

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- ✿ To understand the physical, chemical, and transport processes of the upper troposphere and the stratosphere and their control on the distribution of atmospheric species such as ozone
- ✿ To assess possible perturbations to the composition of the atmosphere caused by human activities and natural phenomena (with specific emphasis on trace gas geographical distributions, sources, and sinks and the role of trace gases in defining the chemical composition of the upper troposphere and the stratosphere)
- ✿ To understand the processes affecting the distribution of radiatively active species in the atmosphere, and the important chemical-radiative-dynamical feedbacks on the meteorology and climatology of the stratosphere and troposphere
- ✿ To understand ozone production, loss, and recovery in an atmosphere with increased abundances of greenhouse gases

UARP, the Upper Atmosphere Research Program, has a number of long-term objectives. The first one is to understand the physical, chemical and transport processes in the upper troposphere and the lower stratosphere, and their control on the distribution of atmospheric species. Another one is to assess potential perturbations to the composition of the atmosphere, to understand the processes affecting the distribution of radiatively active gases. And the third, of course, is to understand ozone production, loss, and recovery.

## ➤ Main Science Questions

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### **How will stratospheric ozone respond to the reductions in the atmospheric abundance of ozone-destroying industrial chemicals?**

- ❖ **As halogen burden falls in response to regulation, stratospheric ozone should begin to recover**
- ❖ **Recovery will be influenced by changing abundance of water vapor, methane, sulfate aerosols, and changes in dynamics and temperature**
- ❖ **Thus, for a given halogen burden, stratospheric ozone amounts will not be the same in the future as found for that same burden in the past**

There are a couple of main science questions that are the pressing issues at the current time. But for some of these, they're actually long-standing questions. Because it actually is the heart of the research. How will the stratospheric ozone respond to the reductions in the atmospheric abundance of the halogens—the ozone-destroying chemicals? The Montreal Protocol has been in effect for a number of years. We've actually begun to see the growth of some of these gases tailing off in the lower atmosphere. So we want to understand as this halogen burden falls, will the stratospheric ozone actually begin to recover. Or will this recovery be influenced by the changing abundance of the radiatively important gases. Will those gases, in fact, change the temperature and impede the recovery of the ozone. These are critical current issues.

## ➤ Main Science Questions

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### **How does the chemistry of atmospheric trace constituents respond to and affect climate?**

- ✧ **Need to understand the spatial and temporal variability of long-lived and short-lived greenhouse gases for radiative forcing of climate**
- ✧ **Plausible changes in water vapor, methane and temperature could impact the expected recovery of upper stratospheric ozone**
- ✧ **Will the build up in CO<sub>2</sub> and other greenhouse gases exacerbate ozone loss due to chlorine activation in Arctic winter?**
- ✧ **Will the hydrological cycle accelerate and increase the frequency and intensity of lightning and the abundance of tropospheric NO<sub>x</sub>?**

Here's the other one. How does the chemistry of the atmospheric trace constituents respond to and affect climate? This is understanding the spatial and temporal variability for the radiatively important gases. But we also need to understand that for radiative forcing, not just for ozone production and loss and keeping the stratosphere above us. I've said some of these possible changes in the water vapor, methane and temperature could impact the recovery. Will the buildup of CO<sup>2</sup> and other greenhouse gases exacerbate ozone loss due to chlorine activation in the Arctic winter? That's partially a temperature issue, in addition to the halogen issue. Then will the hydrological cycle accelerate and increase the frequency and intensity of lightning and the abundance of tropospheric NO<sub>x</sub>? So there really are a lot of remaining science questions, despite the fact that this program has been in existence I think more than twenty years.

## ➤ UARP Implementation-Program Structure

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- ✧ Aircraft-borne, Balloon-borne, and Rocket-borne Measurements (~50%)
- ✧ Ground-based Measurements (~25%)
- ✧ Laboratory Studies (~20%)
- ✧ Process-scale Modeling, Assessments, Misc. (~5%)

### APACHE—Airborne Polar Aerosol & Chemistry Experiment —Toohey, Newman, et al

How rapidly does chlorine activate?

Payload	ClO	-	30 lbs
	O <sub>3</sub>	-	30 lbs
	CO <sub>2</sub>	-	25 lbs
	Cl <sup>-</sup>	-	
	N <sub>2</sub> O	-	
	Particles	-	30 lbs
	P <sub>1</sub> T <sub>1</sub> H <sub>2</sub> O		

Total wt 200-250 lbs

Area of operation—Northern (southern)-most latitudes fly in polar stratospheric clouds



Ames Research Center

Those are the fundamental objectives, both long-term. And I think some of them are pressing science issues that the program is dealing with. I went out and pulsed the science community and a couple of people that I know have been thinking about UAV missions and what could be done, one of which was Darren Toomey. We described and discussed the payload that would include a number of the kinds of things that we currently measure on the ER-2—the ClO, the ozone, CO<sup>2</sup>, chlorine, and that should be pressure, temperature, and water (on the slide). In the discussion with Darren, he and I both believe that perhaps you could do this with a weight of somewhere between 200 and 250 pounds. We sort of added up the existing weights, as we remembered them, for some of the instruments that have been built, particularly under the ERAST Program. This would continue to investigate the Polar Regions and to understand the processes that impact polar stratosphere clouds, and the chemistry in the northernmost and southernmost latitudes, and hopefully to fly directly in polar stratospheric clouds. That would entail getting above the ER-2, although in the Antarctic, the ER-2 did manage to get into the polar stratospheric clouds.

Potential UAV Missions – Paul Newman

<http://hyperion.gsfc.nasa.gov/Other/hawk/Hawk.html>

**Ozone Hole Mission** – Examine causes of ozone loss in Southern Hemisphere. Provide detailed understanding of balance between polar processes and local chemistry.

**Measurements** – HCl, ClONO<sub>2</sub>, NO<sub>y</sub>, HNO<sub>3</sub>, H<sub>2</sub>O, particles, T,P, winds, position

**Tropical Mission** – Examine tropical tropopause and the distribution of water vapor, particles, and other trace gases and the transport of these gases into the lower stratosphere.

**Measurements** – Water vapor, CN, particles, radiation, cloud LIDAR, ozone, CO<sub>2</sub>, N<sub>2</sub>O, T, P, winds, position

I also talked to Paul Newman, who has a website which I'm going to give you. He's written up a couple of ideas for a couple of missions. He, too, wants to investigate the Polar Regions, or thought that would be a good thing to continue to probe and understand what's happening there as the halogen amounts decline. But he wants to take off from Dryden and fly down there all the way—and some of those aircraft we saw this morning I guess can actually do this—and then turn around and come back and land back here at Dryden. That was about a 39-hour flight. So I thought that was very interesting. I said to him, do you think we can record 39 hours of one-second data? But, you know, we're projecting the future here. So some of the limitations will, in fact, go away.

Okay. So this is the website. [<http://hyperion.gsfc.nasa.gov/Other/hawk/Hawk.html>] That's important so you can get a little more information from Paul. The first one I've already talked to you about. For the tropical mission, there is a whole range of issues around the tropical tropopause and the exchange

between the lower atmosphere and the upper atmosphere. Examining the tropical tropopause and the distribution of water vapor particles and other trace gases and understanding the transport—how do these gases generated at the surface make it to the stratosphere? We listed a number of things we thought we would like to have: pressure, temperature, winds and position are kind of a given. We have to know where we are when we're doing the sampling. He envisioned that you'd take off out of Dryden and you'd go all the way out to the eastern Pacific somewhere and turn around and come back. So you would do a very long transect across, above, and below the tropical tropopause.

What I discussed with the two of them were other missions with sub-sets of that long list of instruments. Because as soon as you have all those parameters that you want to measure, the payload gets very large. It's very much like what we currently fly on the ER-2. I am told that for the accent mission that's in progress on the B-57 there are 23 instruments on board. That has been the way the program has been conducted, because we want to measure almost everything we can to understand the inner connections and the effects of one trace gas cycle on another one. But there are other missions that you could do with sub-sets to understand, for example, the polar stratospheric cloud chemistry where you might only measure nitrates and chlorine, not necessarily every single thing that's there.

So I think there are some very good things that can be done. There has been a long-standing need. It goes back to the Truckee Report wherein this program defined a need for high-altitude, long-duration flight. And it was, of course, to get above the ER-2 altitudes—to fly at 100,000 feet, to make measurements where the satellites don't usually do a very good job, or at least they didn't in those days, and where the present aircraft can't quite get to. We have this range in the atmosphere that's not very well sampled. We thought a much higher altitude and long-duration aircraft would be important. Also these platforms would be useful in what are hazardous regions, that is flying over the Arctic and the Antarctic. We asked those ER-2 guys to keep doing that in the single-engine airplane. It's a very reliable platform, certainly, but it's still a very hazardous thing to be doing on a regular basis.

Steve Wegener: Thank you, Estelle. This atmospheric chemistry community is where I came from. And they have really pushed the ER-2 to its limits. There is not enough weight-carrying capacity on the airplane for a lot of the missions the scientists—this community—might want to do. We've kind of maxed the airplane out in many respects. And, as you can see, the missions that Paul suggested here would more than tax the extended capabilities that are promoted by the Global Hawk people. So I think the atmospheric science community will use all the capability that we have, and they're ready to go now.

Our next speaker, Dr. Vic Delnore, is the FIRE Program Manager. FIRE is the First ISCCP Regional Experiment. ISCCP is an acronym for the International Satellite Cloud Climatology Project. This is part of NASA's Atmospheric Radiation Science Program. Vic is from the Atmospheric Science Division at Langley. He's been involved in several large meteorological and marine field campaigns. Vic is also a commander in the Naval Reserve helping to coordinate resources with the Naval meteorological and oceanographic command. Vic's going to talk to us about the potential UAV science roles in radiation science.

ERAST: Oct 13, 1999

Vic Delnore, **FIRE** Project Manager

(**FIRE** = **F**irst [**I**nternational Satellite Cloud Climatology Project]  
**R**egional **E**xperiment)

**FIRE's Charter:** Conduct experiments to:

- *Study the effects of clouds on climate*
- *Facilitate the modeling of clouds in global climate models*
- *Support NASA's Radiation Sciences Program*
- *Link satellite retrievals and in situ measurements*
- *Understand the physics of clouds and cloud processes*

Vic Delnore: FIRE's charter is to study the effects of clouds on climate, facilitate the modeling of clouds in global climate models, support NASA's Radiation Sciences Program, of which Bob Curran is the Program Manager, and understand the physics of clouds and cloud processes. One mission that I did not put up there was to help to validate satellite retrievals of meteorological and climatological parameters. To do this we are the field campaign part of one of the slides that Bob Schiffer showed a few talks back. I also want to mention that if you paid attention to Bob's slides, he gave some projections of what sorts of uncertainties there would be over the next five or ten years. He assigned probably as much or greater uncertainty to the knowledge of clouds and their effects as to any of the other parameters. It's really important that we learn about clouds. Because the knowledge of clouds seems to be the weak link in the global climatological models right now.

This figure [not available] is just my way of getting across to you the basic problem of radiation sciences. There is a lot going on. It all starts with the sun. And then I've got these arrows running all over the place to represent scattering, absorption, and reflection at different parts of the spectrum. We're trying to help sort this out. And those boxes that I've got there—those are some of the places that you might want to send UAVs or aircraft or other balloons, whatever, or do ground base sounding to try to find out what's going on—try to measure the radiances up and down—try to measure the particle sizes—try to measure the distribution of the particles. What's the liquid water content? How much moisture there is really in the form of ice?

## CRYSTAL--Cirrus Regional Study of Tropical Anvils and Layers

### *BASIC QUESTIONS to be explored in CRYSTAL:*

1. How best to improve the modeling of clouds in Global Climate Models?
2. What are the processes at work in the life cycle of clouds?
3. How can we best observe tropical cirrus cloud systems in a large-scale context for climate research?
4. How do tropical cirrus cloud systems impact local, regional and global circulations?

When and Where: 2001, Florida Everglades; 2003 Tropical Western Pacific.

Let me describe for a few minutes the next couple of field campaigns that we're anticipating. In fact, there's a planning meeting the day after tomorrow in Chicago which will involve a lot of scientists that are sort of steering the science of CRYSTAL [Cirrus Regional Study of Tropical Anvils and Layers]. I want to underline what both Bob and Cheryl mentioned earlier. The field experiments, the field campaigns that FIRE undertakes and CRYSTAL, which I'll talk about in a minute, are strictly principal-investigator driven. It's important. It's sort of a grass roots campaign from the ground up. Scientists get together and propose various missions to do in the overall context or guidelines of the NRA which gets issued. And each PI is sort of autonomous in contributing to the overall effort. Anyway, on CRYSTAL, let me jump to the bottom of this—when and where, because that's what's most important. Two thousand one, Florida Everglades and 2003, the Tropical Western Pacific. What we're going to try to do is investigate the things that I have listed up there—how best to improve the modeling of clouds in global climate models. What are the processes at work in the life cycle of clouds? How can we best observe tropical cirrus cloud systems in large-scale context for climate research? How do tropical cirrus cloud systems impact local, regional and global circulations? CRYSTAL has two parts: two years from now in the Florida Everglades, four years from now in the Tropical Western Pacific. The reason for the 2003 campaign is it had originally been scheduled for 2001. However, Cloud SAT, EOS Chem, Picasso, Sena—various other satellites are going to be up at that time. We want to take advantage of that, and we also want to contribute to their validation and calibration programs.



This is the basic logistics plan for CRYSTAL. It looks a lot like one particular one of the UAVs. It's supposed to be representative of all of them. Also, I don't really mean to imply it has to be a UAV. The piloted version of one of the aircraft that we saw this morning could very well fit that role under certain circumstances. Anyway, what I've got here is RS (for remote sensing), IS (for *in situ*). By the way, this would be the cirrus that comes off of a convective system, say, in the tropics. The idea for CRYSTAL is to have an island station—this would be one of the DOE ARM sites. This would be the NOAA Ship Brown. This would be a cooperating Japanese oceanographic research vessel. [Points to ships in the figure.] The three of these would form a triangle in the ocean. We would have a large triangle. The two ships, of course, would be mobile. They would move around with respect to the island in order to take advantage of whatever prevailing convective systems we had. Likewise, you would have an aircraft—the DC-8 or a similar vehicle—as a remote sensing aircraft. It would fly underneath the cirrus looking up. You would have the ER-2 as a remote sensing aircraft with sensors looking down. You would have a WB-57 flying through cirrus. The *in situ* aircraft would be gathering information on distribution of particulate sizes and water content—this sort of thing. Hopefully, there would be another *in situ* aircraft—a Citation or a Lear or something. And then over here—this would be perhaps the end car Electra or similar aircraft equipped with the ELDORA tail radar, Doppler radar. And this could be useful at various places in the column. Of course, there is satellite data. So that would be CRYSTAL.

This is a DOE slide [not shown], I think, that I can't really talk too much to. I was just given it yesterday. However, there are some people in the group here—Warren Gore from Ames and also Will Bolton from Lawrence Livermore—that I think could answer questions on this. But basically this is an example of a recent successful mission in radiation sciences. And the stated aim is right there. The logistical result is right here. What you've got here is one of the UAVs—the Altus, in fact. I understand that this box was inside somewhere. Then each of these radiometric measuring devices was a broadband radiometer, one of them looking up and the other in the belly looking down. And the result was albedo at

over a very broad spectrum of wavelength. And the different colors represent different flight days. We can go into more detail, you know, during the question period.

## Advantages of ERAST Aircraft for Atmospheric Radiation Science Research

- Long Endurance: Monitoring Roles
- High Altitude: Above the Clouds
- Station-Keeping: Stationary or Drifting Air mass Measurements
- Range of Speeds: Good for *in-situ* measurements
- High Payload Efficiency: Carry lots of sensors

I've listed up here some of the advantages of ERAST aircraft. And, again, I'm using the broader term instead of just UAV because there is the piloted version. Some of the characteristics here I've listed. And then opposite them or next to them I've put some of the things that I think would be useful in radiation sciences. Long endurance—that gives rise to monitoring roles. High altitude—we can get above the clouds. Station keeping—I understand you can set the flight profile of these vehicles to do two different types of measurements. That would be very, very interesting, especially if you combine the long endurance and the high altitude and the station-keeping abilities, you have the makings of a very good capability there. Also the range of speeds—that's very good for *in situ* measurements. Also the high payload efficiency. In other words, for every crew member that you can leave on the ground, you can carry a lot more sensors. So that's very, very appealing.

## **Challenges for ERAST Aircraft in Atmospheric Radiation Science Research**

- Staging, Ground Support
- Wx conditions for Takeoff/Landing
- Airspace Use
- Flight in Meteorologically Interesting Regimes:
  - Icing in Clouds
  - Turbulence, Gusts at the edges of Clouds
  - Cloud Condensation Nucleii: Salt Spray, Dust & Ash

These are the challenges. These are some of the things that are going to have to be overcome in order to make this a really viable system for use in radiation sciences. We're going to have to cut down the staging and ground support costs. Some of the numbers that I saw up there were pretty scary. Those have to come down. Weather conditions for takeoff and landing. As we saw this morning, the reason we all had to roll out of bed at a real early hour was to take advantage of the calm conditions that were expected and which, indeed, did occur for takeoff and landing of at least the first vehicle. I think the second vehicle had a much, much wider cross-wind tolerance range and all that sort of thing. But you have to figure, as was mentioned earlier today right here in this room, a lot of times the things that we're looking at—in fact, Burt mentioned this—the conditions that are going to be there when you want to do a science mission mean that you're going to have to be able to take off in gusty conditions. So that is really going to have to be addressed in order to make these vehicles useful. The airspace use. That's going to really have to be worked with FAA and overseas authorities as well. Flight in meteorological interesting regimes—in particular, if you're doing cloud science—one of the things that you're really interested in is ice particle measurement. Well, are these aircraft going to ice up real bad? Is it going to really damage that very, very thin wing fabric structure there? That has to be worked out. Also, flight in turbulence and gusts. This is what you get at the edges of the clouds. And we want to make measurements at the edges of clouds. Also, cloud condensation nuclei. What problems are there going to be when you deliberately fly one of these aircraft into salt spray at real low altitudes, into dust and, say, volcanic ash. These are all part of the radiation science equation. Because we're trying to measure what comes down from the sun through the filter of the atmosphere. And if it's dust from the Sahara and ash from a volcano, we have to be able to put an aircraft into that. And how is that going to work with a UAV?

Steve Wegener: Next up, Dr. Ernest Paylor, who is the Solid Earth and Natural Hazards Program Manager for the Office of Earth Science [OES] at NASA Headquarters. He's also the Manager under a DoD hat for the Pacific Disaster Center. Ernie will talk about the OES Applications Program and the potential roles for UAVs in that.

Dr. Ernest Paylor: [Slides unavailable] This talk really should have followed Bob Schiffer's. It's really a program-level talk. It's going to discuss the Applications Commercial and Education [ACE] Division and a new initiative that we have at NASA Headquarters to deal with applications.

But what I'll be talking about today is what we call the ACE Program. It really is not only a division within NASA Headquarters in the earth sciences area, but it is also a major new initiative that we have put forward. It's about a year and a half old. It's an aggressive new strategy devoted to significantly increase the applications of the earth sciences enterprise's science and technology for more pragmatic uses—societal uses, economic uses to ensure maximum return on taxpayer investments.

I won't talk about this too much because Dr. Schiffer talked about the earth science enterprise's missions and goals quite a bit. What I will point out are these three goals. And it turns out that Bob Schiffer talked about my first point about expanding our scientific knowledge of the earth system. The other two goals that we have in the earth sciences area are disseminated information about the earth system and also enabling the productive use of earth science and technology. It's really these two issues and, in particular, this last one that the ACE Program or the ACE Division is addressing. The inset picture on the right [not available] is a September 20, 1997, snapshot by the TOPEX/POSEIDON satellite of El Niño as it was occurring back in that time period. As Dr. Schiffer talked about some of the physics behind the El Niño phenomena, from the applications perspective we're looking at the impacts of El Niño on, for example, the fisheries along the West Coast of the Americas, meteorological impacts in the United States, potential fire danger in Australia and also in Indonesia. So those are more the types of applied science issues that the Applications Program is dealing with.

The science themes—I just want to point out that these five themes represent the fundamental underpinnings of the Applications Program. It's the science and technology that's coming out of this basic-science endeavor that allows us to apply our science or results or data and our techniques to more pragmatic uses.

ACE's mission is to realize the full value of NASA earth science enterprise investments by encouraging a broader use of the science and technology that comes out of the program. But we really want to extend the use of our science and data to routine decision-making in the public and private sectors. I emphasize the public and private sectors because we are working with the commercial industry in this endeavor. We do this really by developing new capabilities and applications through applied research and development. And, again, I emphasize applied research because this is a research program. It's not an operational type of activity. We work directly with our user community—the potential users in this activity. But we've also realized that in order to make this all happen we definitely have to encourage and utilize the commercial industry quite a bit. So they're actually teaming up with us on these activities. When we get to a point where an applied research project that we might be working on is ready for routine applications, that's not really our job to do that. But we hope that the commercial industry is there so we can hand this off to them and they can implement it on a routine basis for the end customer. We've realized that educational training is a very important component of this activity, not only to the ultimate decision-makers, but also to the general public at large. Finally, we hope that by going through this process that we are identifying unmet challenges that we can use not only in the Earth Sciences Program, but to develop future earth science missions and research objectives.

This chart [not available] is just a graphical form of what I just talked about. But I'll use it to point out a few things. One, as you can see over here on the left-hand side—these are really the science themes that we just talked about. We feel that there is a fundamental linkage to this market adoption on the right-hand

side. That's really the user community out here that's represented by this user beneficiary box. And the governmental sector, the international sector or the commercial users, as well as these other users—they represent an enormous, enormously untapped user community for our science and data. That's really what we're trying to tap into. This box right here represents the heart of the applications effort. And it really is what develops the program's content. It's basically forming a bridge between this market adoption and the science that we're trying to do. And like the science program, the research program that's designed around research themes, the applications area is, likewise, formulated around what we call applications themes. And these were designed and selected by a committee of these people down here based on national priorities, uniqueness to NASA, and several other activities. So we had a long discussion with this entire group that helped us come up with these type of these applications themes. As I said earlier, we work directly with the users in trying to understand what their requirements are. We look at ways or investment strategies to try to figure out—is the science mature enough to do what this application requires? Are there value-added industries that can provide the same type of information at that point? And as we go through this process, we come up with strategies on how to implement this program, whether it be through teaming arrangements with industry or with government sector or with other U.S. government agencies or international agencies, or whether we do it through data purchases or some other solicitation mechanisms. But we go through this process or we're establishing this process, I should say, to go through this activity. We've realized and we've known for a long time that there are ways that we have to interface with our community out there. One is through knowledge transfer—and that involves the education and training process. And the other one is actual dissemination of information and data. And it's our hope that we can do a much better job of connecting our potential users with the science and applications that we have.

These are the applications themes that I talked about earlier. At the high level we have food and fiber. Talks about things like precision agriculture, natural resources, disaster management through all types of different natural disasters, environmental quality, urban-energy infrastructure, and also human health and safety. These represent the basic core information content or program content of the ACE activity.

Those applications themes look very much like the science themes. I put this chart up just to show that the basic science programs that we have interrelate with the applications themes—for example, the Solid Earth Natural Hazards Program feeds into at least four of these areas in the applications themes.

A few other examples. We had a talk earlier about coffee beans in Hawaii. But through our science programs, trying to understand terrestrial ecology and biogeochemistry, and the carbon cycling—we have techniques. We have technologies that can be useful in agriculture for identification of crops, invasive species, to do a better job and help in the planning process for watering and fertilization, and to help bring down the bottom line in terms of cost in agriculture.

Wildfire is another example. Through trying to understand terrestrial ecology-type applications, we can do now better jobs of understanding fuel loads and being able to model potential wildfires, not only model the fuel loads themselves but detect and monitor wildfires as they're occurring and be useful in the deployment of resources in the field in real emergency situations.

In our Solid Earth Program we're trying to understand eruption mechanisms, the plumbing system of volcanoes to try to figure out really how they work internally. In doing so, we develop techniques and technologies to monitor precursor signals that include ground deformation of volcanoes themselves, volcanic out-gassing, as well as thermal signals. These can be very useful for understanding or in emergency-management situations for warning of volcanic eruptions, and also volcanic plumes—being

able to monitor volcanic plumes, their evolution—and be useful for warnings for aircraft safety, for example.

In flooding, our interest in understanding the dynamics of watersheds and flood plains leads to a lot of new techniques and technologies that can be useful for flood-plain management, flood-inundation-level monitoring using remote sensing techniques, as well as flood-plain mapping. Just as a side issue, one of the projects we're working with right now is with the Federal Energy Management Agency (FEMA). It's been mandated by Congress to go back out and re-map all the flood plains for the National Flood Insurance Program. They've estimated this job to cost almost \$900 million over a five-year period. It's an enormous budget expenditure that they had not planned for in their budget. So we're working with them on evaluating different techniques and new technologies for flood-plain mapping that include Light Intersection Direction and Ranging [LIDAR] techniques, interferometric search and rescue [SAR], for more precise mapping of the flood plains and incorporating that with other types of structural information, as well as finding out how those types of data sets affect hydrologic models to come up with better predictions of 100-year and 500-year flood plains and, therefore, re-map and do a more accurate job of coming up with the flood-plain maps that the Flood Insurance Program needs.

Obviously, we are not doing this alone, even with our current set of partners. We're looking at the other agencies participating in this activity, as well as the private sector. State and local governments are major players right now in this—the international organizations as well as universities. The intention here is to at least provide this problem-solving capability at the local level for decision-makers.

One of the first major activities in this is to try to hook up all 50 states in the United States. In terms of state and local governments, there are many different levels of expertise right now able to utilize some of the science coming out, not only of NASA but of other programs as well, and utilize remote sensing capabilities. But our intent through this activity is to provide coast-to-coast data for communities to solve practical problems and basically contribute to informed decision-making. So, as one of our first steps we're trying to reach out and provide these types of capabilities to all 50 states and then from there to the international community as well.

Since this is a conference on UAVs, I thought I would summarize by talking a little bit about potential for aircraft observations in this ACE Program. Now Cheryl talked about some of the airborne activities and also Bob Schiffer. But I'd like to say that airborne observations and airborne platforms will be a very large part of the ACE Program as we move out into the future for two reasons. One is as a test bed for technology and science. We really do use our airborne programs as a test bed for applications development, for instrument development, and will continue doing that into the future. But secondly, as a regular mechanism for providing routine observations.

Now the airborne sciences or the airborne systems fill a niche. And I feel that they're complementary to the satellite observations and also the ground observations we make. They provide the nice link between these two sets of observations. Now they're particularly useful for high-resolution imaging, as was pointed out earlier, but also event-based imaging. What I'm talking about with event-based imaging relates in particular to the natural disaster area or disaster management. If you're talking about response-type operations—preparedness and response—they can be very useful for quick response, long-loiter capabilities for phenomena to evolve over several day periods, as well as providing the continuous high-temporal frequency monitoring of these events. But the considerations that we have to think about, as the last speaker pointed out, are the costs. We have to consider the cost of deploying this. Is it more cost effective to go to our regular aircraft versus ERAST-type unpiloted vehicles. These are all considerations.

The FAA regulations are a big factor, in particular, for some of the activities that we're talking about. Because many of these phenomena occur over urbanized areas. If we can't fly over these areas, then we have a serious problem. Are the instruments that we need available? I don't think a lot of them are right now. I believe there are programs going on right now that are developing new instrumentation. But the constraints that we have to think about—power, mass, and volume—are very large considerations in developing technologies and instrumentation for these aircraft. It's through the ERAST-type program that I think we're going to break down these barriers. Over the next five or so years we look forward to being able to utilize these systems for this type of research.

Steve Wegener: Our last speaker is William Bolton, who is the Deputy Director of the UAV ARM program, another acronym—Unmanned Aerospace Vehicles is UAV and Atmospheric Radiation Measurements is the ARM part of it. He's with the Sandia National Lab in Livermore. Will has led several UAV experiments, including this most recent one—the tropical cirrus mission out of Hawaii with the Altus UAV. Will's going to share some of his real world insights into flying UAVs and some of the applications there.

## UAVs in Climate Research: Atmospheric Radiation Measurement-UAV Program

W.R. Bolton

ARM-UAV Deputy Technical Director

William Bolton: My plan was to spend the time that I have here to tell you a little bit about the ARM-UAV Program—just a couple of slides so you understand what it's about, talk about the Kauai deployment that we did this last April and May in Kauai, Hawaii, and close with some comments based on our experience.

### ARM-UAV programmatic approach



*The ARM-UAV program was structured to utilize existing capabilities and to foster the development of improved instrument and platform capabilities within the framework of an experimental program accomplishing scientific goals.*

ARM-UAV was enabled by increased interest in and funding for development of small, high altitude, long endurance UAVs utilizing:

- **Composite structural materials and construction**  
( Weight efficient structures with complex aerodynamic shapes )
- **Microelectronics**  
( Powerful, low-cost, ubiquitous processing )
- **Computation**  
( Sophisticated analysis and design )

Bolton 10/13/99

I wanted first of all to point out the overall programmatic approach. The point is that the ARM-UAV program is constructed not to do development of platforms—to do some instrument development, but to do all of this in the context of a program that's accomplishing scientific goals. We're not a development program in that sense. We're a user of the technology as it becomes available. I pointed out some of the technologies here [see slide] that I thought were key in facilitating the availability of aircraft to meet the ARM-UAV needs.



**Department of Energy**  
Energy, Security, and Environment

## ARM-UAV Program



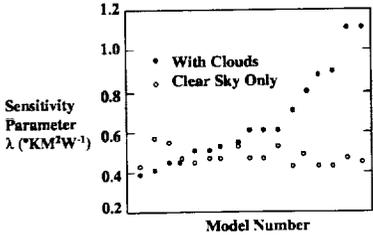
**Atmospheric Radiation Measurement - Unmanned Aerospace Vehicle (ARM-UAV)**  
*Investigating the largest source of uncertainty in global climate change predictions:  
 The interaction of solar and thermal energy with clouds in the atmosphere*

GCMs

General Circulation Models are used to Study the response of global climate (e.g., "greenhouse" warming)

Comparison of 17 world-class GCMs showed clouds to be the largest source of uncertainty



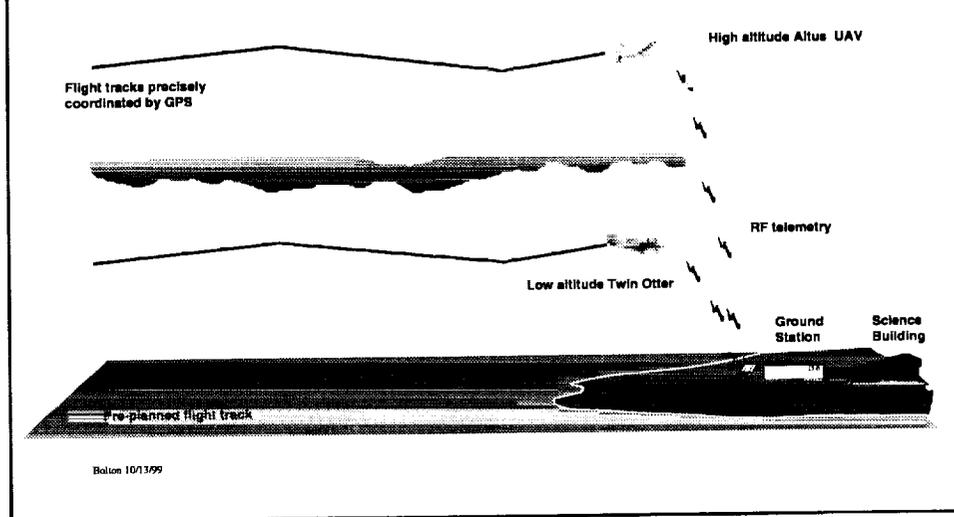


Model Number	Sensitivity Parameter λ (°KM²W⁻¹) - Clear Sky Only	Sensitivity Parameter λ (°KM²W⁻¹) - With Clouds
1	0.45	0.45
2	0.48	0.48
3	0.50	0.50
4	0.52	0.52
5	0.55	0.55
6	0.58	0.58
7	0.60	0.60
8	0.62	0.62
9	0.65	0.65
10	0.68	0.68
11	0.70	0.70
12	0.75	0.75
13	0.80	0.80
14	0.85	0.85
15	0.90	0.90
16	0.95	0.95
17	1.00	1.00

Bolin 101399

This is a slide that sort of sets some of the background for the ARM-UAV Program. It has been pointed out several times in the past how clouds are probably the largest single source of uncertainty in our understanding and modeling of the global climate change. The ARM-UAV Program is designed to address that largest source of uncertainty. The approach we're taking is to utilize airborne measurements primarily from unmanned aerospace vehicles—hence the name UAV in the title of the program—to carry aloft primarily radiometric payloads to help our understanding of the interaction of clouds and solar energy in the earth's atmosphere. The little box in the lower right-hand corner here illustrates an intercomparison of 17 world class general circulation models and illustrates that with clouds there's a fair degree of uncertainty or disagreement between the models in terms of the predicted warming in response to the increase in global warming or greenhouse gases.

## ARM-UAV Measurement Strategy



I wanted to give you a quick view of our measurement strategy. That is basically to use two platforms, one above the clouds, one below the clouds. This little wiggle here is intended to represent a layer of clouds. [Points to figure.] Both of those platforms are carrying matched sets of radiometric instruments to measure the effect of the clouds and also to measure the effect absorption in clear skies to help understand the role clouds play in effecting the transport and absorption of energy in the atmosphere. The data from these two platforms is telemetered to the ground and made available to the principal investigators and scientists in real time so that they can observe the data, monitor the performance of their instruments and make sure that they're getting what they want, and then redirect the mission in real time if there's opportunities to do that.

## ARM-UAV has developed payloads for a variety of aircraft



- Atmospheric Radiation Measurement - Unmanned Aerospace Vehicle (ARM-UAV)  
*Integration of sophisticated payloads (lidar, radiometers, in situ meteorological;  
including on-board data handling and RF telemetry)*

- Radiometric payloads flown in several major campaigns :

*Gnat (UAV)*  
(11/93, 4/94)



*Twin Otter (piloted chase aircraft)*  
(7/95, 9/95, 4/96, 9/96, 9/97, 4-5/99, 6-7/99)



*Egrett (piloted high altitude aircraft)*  
(9/95, 4/96)



*Altus (UAV)*  
(9/96, 9/97, 4-5/99)



Bolton 10/13/99

Over the years that the program has been in operation we've prepared payloads and flown them on a number of platforms. We started off with the Gnat—General Atomics Gnat airframe, a relatively small airframe—which carried a smaller payload than we would like to have carried. But it was available at the time and got us started. We did a two flight series—an engineering flight here at Dryden in '93 then a subsequent series of flights in '94 at the Oklahoma CART site. CART stands for Cloud and Radiation Test Bed. That's a DOE facility that's very heavily instrumented in north central Oklahoma and has been the focus of a lot of our activities. One point I wanted to make while we're talking about CART is that's general use airspace. It's over Oklahoma—relatively sparsely populated, but, nonetheless, it's general use airspace—not a restricted area. We've been able to work with the FAA to allow us to do these operations over north central Oklahoma. For our flights so far, because of FAA requirements and general use airspace, we've had a chase aircraft—in our case, a DOE-owned Twin Otter aircraft. We instrumented that aircraft so it becomes the second instrumented platform. It accompanies the UAV up to 18,000 feet into class A airspace. Above that altitude, the UAV can operate as any other aircraft on an IFR—instrument flight rules—flight plan, and then the Twin Otter is available to operate as a second independent platform which we use in coordinated flight with the high altitude UAV. We also used the Egret for two series of flights. This was basically a surrogate for high altitude UAV before such a high altitude UAV was actually available. We operated a payload just as if it were in a UAV. And most recently we've been using the Altus as the high altitude UAV to carry our payload in three flight series as noted in the chart there.

## ARM-UAV Altus Payload Instruments



### Radiation Measurement System (RAMS) - UCSD Scripps Institute

- Total Direct/Diffuse Radiometer, 7 channels, near UV to near IR
- Total Solar Broad Band Radiometer, 0.2 to 3.9  $\mu\text{m}$
- Fractional Solar Broad Band Radiometer, 0.7 to 3.3  $\mu\text{m}$
- Infrared Broad Band Radiometer, 4.0 to 48.0  $\mu\text{m}$
- Zenith and nadir

### Scanning Spectral Polarimeter (SSP) - Colorado State University

- 55 spectral bands, 0.4 to 4.0  $\mu\text{m}$ , nadir only

### Multi-Spectral Pushbroom Imaging Radiometer (MPIR) - Sandia

- Modular, 9 channel, 0.58 to 11.5  $\mu\text{m}$ ,  $\pm 40^\circ$  FOV, nadir only

### Cloud Detection Lidar (CDL) - Lawrence Livermore

- 1.053  $\mu\text{m}$ , backscatter lidar, 5 KHz pulse rate, 20 nanosecond pulse
- Nadir only (in Altus mount)

### Solar Spectral Flux Radiometer (SSFR) - NASA Ames

- Zenith and nadir, fiber optic coupled, 0.3 to 2.5  $\mu\text{m}$

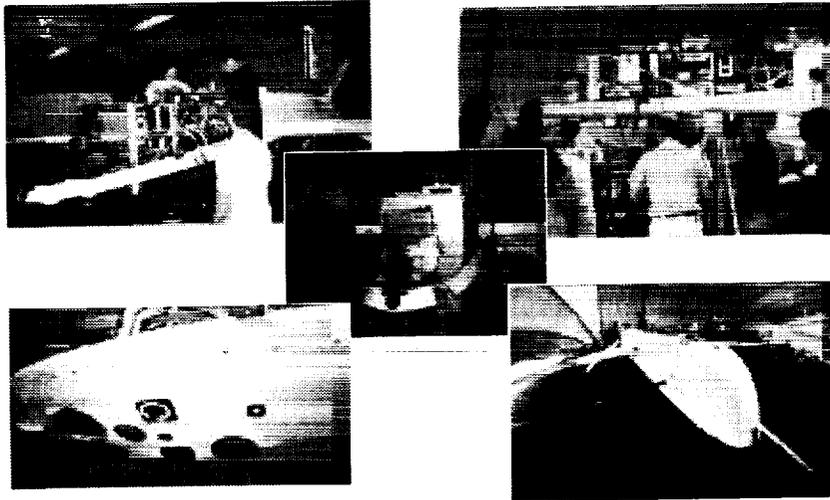
### Meteorological Instruments

- Total temperature, total pressure, frost point hygrometer

Bolton 10/13/99

This is a listing of the instruments that are part of the Altus payload. This is a picture to show you what the payload looks like, as installed in the Altus. This is starting the installation here [points] down to the completed installation here with the instruments in place. We have radiometers on top of the payload as well as on the bottom, just as Vic pointed out earlier, showing the bottom of the aircraft for this installation and the instruments located on the top. In addition to the radiometers, we also have *in situ* measurements of temperature, pressure and water vapor concentration.

## ARM-UAV Altus Payload



Bolton 10/13/99

## ARM-UAV Twin Otter Payload Instruments



### Radiation Measurement System (RAMS) - UCSD Scripps Institute

- Total Direct/Diffuse Radiometer, 7 channels, near UV to near IR
- Total Solar Broad Band Radiometer, 0.2 to 3.9  $\mu\text{m}$
- Fractional Solar Broad Band Radiometer, 0.7 to 3.3  $\mu\text{m}$
- Infrared Broad Band Radiometer, 4.0 to 48.0  $\mu\text{m}$
- Zenith and nadir

### Scanning Spectral Polarimeter (SSP) - Colorado State University

- 55 spectral bands, 0.4 to 4.0  $\mu\text{m}$ , zenith only

### Airborne Cloud Radar (ACR) - JPL/Univ. of Massachusetts

- 95 GHz, 30 cm lens
- Zenith

### Solar Spectral Flux Radiometer (SSFR) - NASA Ames

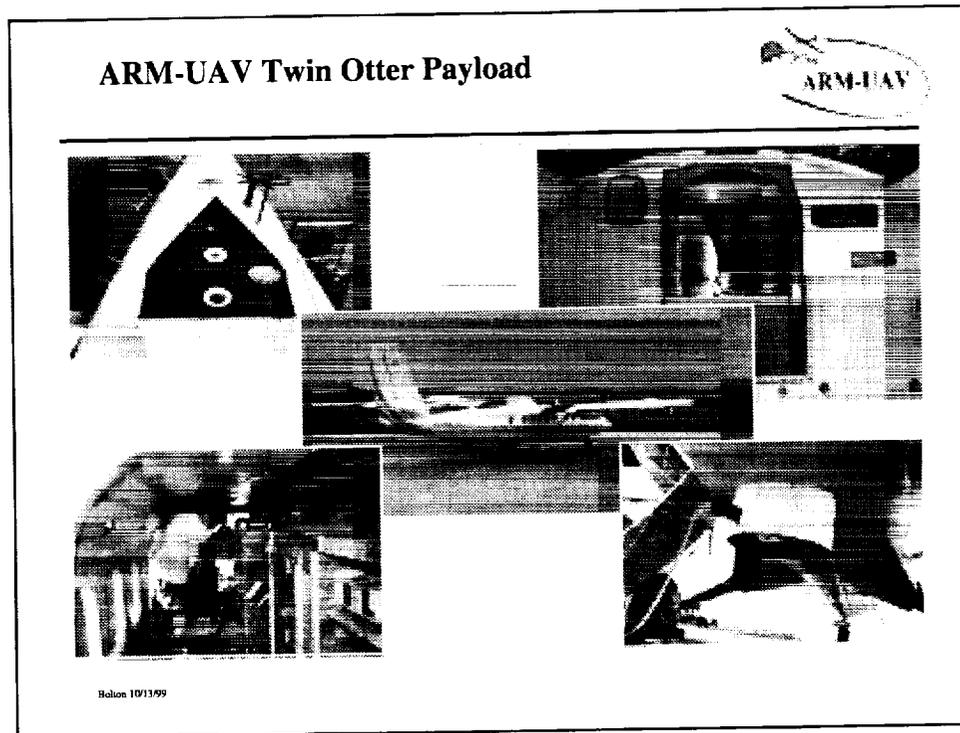
- Zenith and nadir, fiber optic coupled, 0.3 to 2.5  $\mu\text{m}$

### Meteorological Instruments

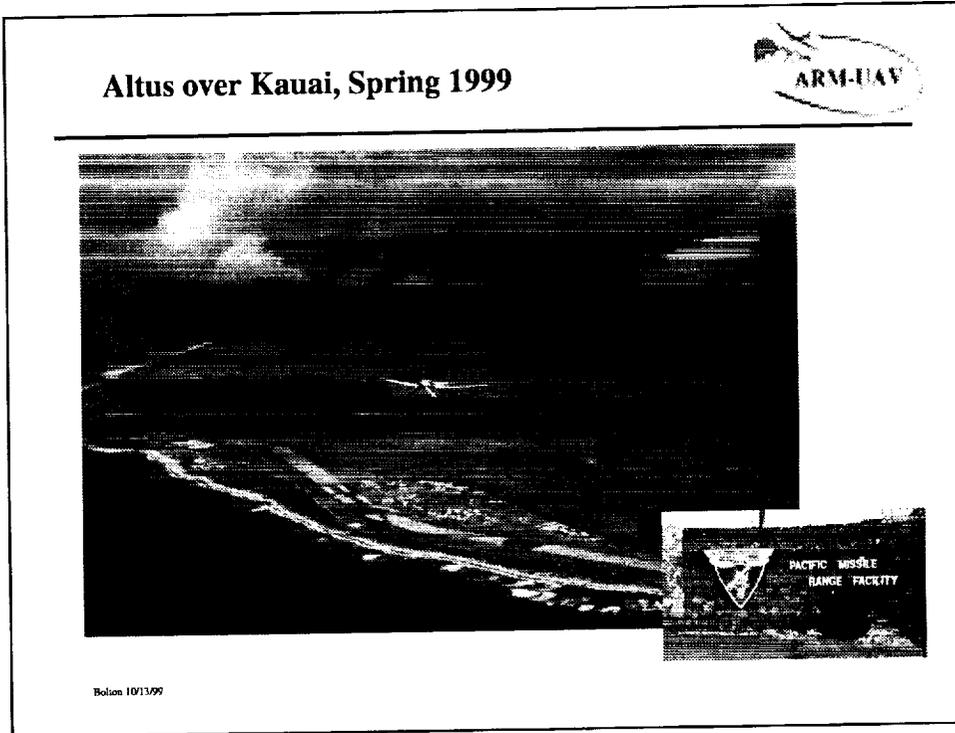
- Total temperature, total pressure, chilled mirror hygrometer

Bolton 10/13/99

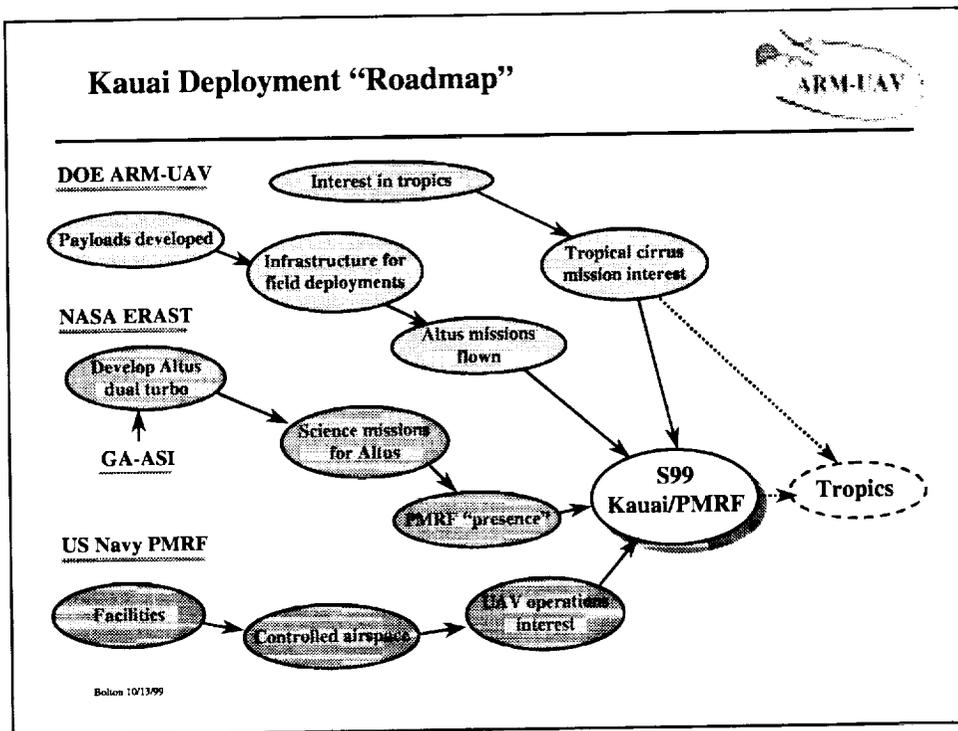
This is a listing of the comparable instruments carried on the Twin Otter. For the most part, it's the same radiometers as fly on the Altus. There are some differences. The Altus has a cloud detection Lidar. The Twin Otter does not have the cloud detection Lidar, but for the most recent flight series had a cloud radar in its place. The Lidar looking down at the clouds from the top—the radar looking at the clouds from the bottom. By virtue of the coordinated flight, both of them looking at the same region of the clouds simultaneously.



This is a photo showing the installation of the instruments on the Twin Otter. These are the up-looking radiometers in a can on top of the aircraft—the comparable radiometers on the bottom of the aircraft. Both of those are added onto the aircraft. The cloud radar horn looking up through the top of the fuselage of the aircraft into the bottom of the clouds. And we have equipment racks in the fuselage of the aircraft. Generally, two payload operators fly onboard the aircraft to operate the equipment located in the Twin Otter.



Now I'd like to move to the Altus over Kauai in the Spring of 1999. These flights were conducted over the Pacific Missile Range Facility [PMRF]. And the PMRF is shown here, and the Altus turning is part of its approach for landing at the PMRF.



This is what I called a road map. It points out the four major participating organizations in this flight series and shows you how it all flowed together to support the spring deployment. The DOE ARM-UAV Program has a long-standing interest in going to the tropics. Moving to Kauai as one of our stepping stones towards the tropics made a lot of sense to us. We have prepared these payloads, flown them on the Altus before. So we were ready to use the Altus for a Kauai flight deployment. The ERAST Program and the Alliance and General Atomics under that program have fostered the development of a high altitude version of Altus that's capable ultimately of getting to 65,000 feet and had the operational capability to serve our needs for a cirrus mission in Kauai this last spring. The fourth organization participating was the Navy's PMRF facility. They have the facilities and the controlled airspace that were well suited for our mission. All four of those elements came together very nicely to support this deployment last spring.

### S99 Deployment site was US Navy Pacific Missile Range Facility, Kauai, HI



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- Ground operations were based in and around the "Clamshell" fabric hangar used by ERAST/Pathfinder

**In hangar:**

- Science facility
- ARM-UAV mission control
- Briefing area
- Altus storage and work area

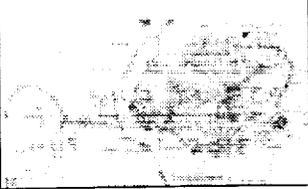
**Adjacent to hangar:**

- ARM-UAV Payload Ground Station and antenna
- ARM-UAV weather data satellite antenna
- ARM-UAV "meteorological" station
- GA-ASI Ground Control Station on ramp
- GA-ASI Ground Data Terminal on ramp

- Flight operations were conducted in R-3101 and W-188

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## The Spring 1999 Kauai Deployment had Scientific and Operational Objectives



### Key scientific issues:

1. Distribution and amounts of ice mass and total water in the upper tropical troposphere
2. Radiative properties of upper tropospheric cirrus clouds
3. Radiative properties dependence on environmental conditions



### Operational objectives: To demonstrate...

1. ... the ability of Altus to carry the ARM-UAV payload to altitude required for tropical cirrus mission at Kauai (~50,000 ft with growth path to 65,000 ft)
2. ... adequate reliability of Altus to take advantage of flight opportunities
3. ... the ability to maintain "vertically stacked flight" with higher UAV altitude
4. ... secondary objectives: coordination with another range facility; deployment to non-CONUS, sub-tropical location

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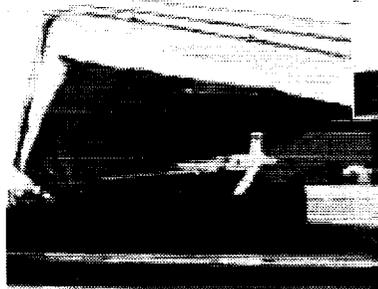
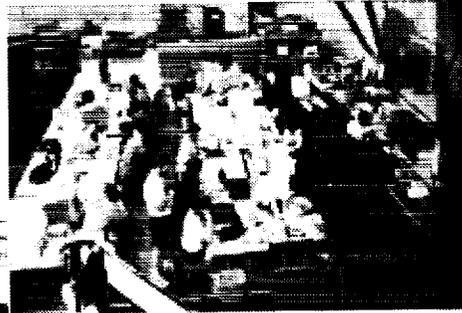
This spring deployment had both scientific and operational objectives. This reflects the first slide I used, indicating that this is not a development program so much as it is a program getting scientific data embedded in a program, taking advantage of developments as they become available. We had a number of key scientific questions dealing with cirrus clouds, their properties, water vapor concentration, radiometric properties, and so forth. In terms of operational objectives, again it's an opportunity to move closer towards the tropics, which will require higher altitude performance from the aircraft. We're looking for an opportunity to show that the Altus can carry the full payload—the Altus payload—up to the higher altitudes to get above the cirrus clouds. We can interface with another range. We can do these operations in a non-continental United States (CONUS) location away from our normal operating facilities and some additional secondary objectives as shown on the bottom.

As I mentioned earlier, the deployment took place at the Pacific Missile Range Facility in Kauai, Hawaii. The little map down here, which may be difficult for you to see, shows PMRF located on the western edge of the Island of Kauai. Our operations were conducted within either restricted or warning airspace. In this environment we didn't need the chase aircraft to accompany the UAV at all times. They really operated as independent aircraft coordinated during the data-taking phases of flight. An overview of PMRF—the fabric hangar was located here [points to slide], the same hangar that was used for the Pathfinder and Pathfinder Plus flights. Immediately adjacent to the hangar were the trailers to support the data acquisition, the antennas, and the ground station for controlling the Altus aircraft.

The "Clamshell" hangar contained the...



...Science Facility...



... and the UAV work area.

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I wanted to show this slide just to show you what the inside of the clamshell hangar looked like when it was configured for our uses here. At one end of the hangar we had our science facility. You can see a number of scientists and engineers monitoring the performance of the instruments, looking at data in real time as the mission is being conducted. This was set up with a little local area data network so everyone had access. They could plug in their computers or work stations and have access to the data in real time. At the opposite end of the hangar was a work area for the Altus aircraft. That's where it was parked overnight, and that's where any maintenance or checking of instruments or checking of the aircraft took place.

## This Joint ARM-UA V/ERAST Campaign Resulted in Many Notable Achievements



### Operationally

- 7 Science flights were conducted during the 4 week flight series
- Total Altus flight time above 50 Kft was approximately 16.5 hours
- First flight series for dual turbo, high-altitude Altus UAV Altus DT: 55 Kft now (65 Kft ultimately)
- ARM-UA V payload flown to highest altitude ever (55 Kft)

The table, titled "Summary of 2011 Flights", contains several columns including "Flight", "Date", "Time", "Altitude", "Duration", "Status", and "Remarks". It lists various flight events throughout the year, such as "Altus DT 55 Kft", "Twin Otter payload", and "CERES/TRMM calibration".

### Scientifically

- Simultaneous "stacked aircraft" measurements with thick (~7 Km) cirrus clouds with cloud detection lidar and cloud radar characterization of clouds
- Simultaneous "stacked aircraft" clear sky measurements
- In-flight intercomparison of instruments on Altus and Twin Otter
- "Calibration" of CERES/TRMM satellite instrument with Twin Otter payload

*... contributing to an improved understanding of the interacting elements of the global climate system*

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This is a summary of the accomplishments of this flight series. We did a total of nine flights. Seven of them we consider science flights—two of them are engineering flights just to check out payloads and make sure that everything was working properly. You can see some of the objectives here. Over 16 hours of flight above 50,000 feet allowed us to acquire a lot of good data in the course of the mission. In particular, we had some very good thick cirrus cloud days, which provided excellent data for us and which we considered a very important data set to get. We feel that this is a very successful flight series, both from an operational and from a scientific standpoint.

## General Comments on UAV Experience



UAVs have provided a good platform for several valuable scientific flight series

- Long endurance ( 26+ hours ) and high altitude ( 55 + Kft )
- Stable measurement platform

UAVs are a rapidly developing technology with further improvements on the way...

- Capabilities ( altitude, endurance, "over-the-horizon", payload, all weather flight, etc. )
- Compatibility with National Airspace System ( e.g., "see and avoid" - chase airplane requirement, other limitations - clear of clouds )
- Utility ( reliability, availability, maintainability )

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Now I'd like to move into the general comments on our UAV experience. I wanted to start off with some rather general comments. First of all, this is a good platform for our uses. We've had some good deployments with it. We've gotten good data. We feel very good about the capability that this aircraft has provided to us. We did a long endurance flight of over 26 hours at in the low 20,000-foot regime. We've done flights as high as 55,000 feet in Kauai with our full payload. So we feel very good about the capabilities there. I noted here that it's a stable measurement platform. By that I mean the motion of the platform is such that it's suitable for the kind of measurements we want to make. Initially there was some concern about whether UAVs would even be a suitable platform for scientific measurements and, I believe, for the kind of radiometric measurements we make. And we've demonstrated that indeed it is. I've got some comparison slides here that illustrate the relative stability of the piloted aircraft and the remotely piloted aircraft. And we feel very good about the stability of the airframe. It's at least as good as, if not better than, the piloted aircraft in that regard. What is stated here is there's been a lot of developments taking place in UAVs, a lot of it fostered by the NASA ERAST Program. We feel that further developments are on the way in ways that I've shown here in terms of compatibility with the National Airspace System, improved capabilities of the aircraft, altitude endurance, payload, and so forth, and utility of the aircraft in terms of reliability, availability—that is, can it be ready to fly every day you want to fly—and maintainability—how many hours of maintenance does it take per flight hour of flight operations. I made a little statement down here which just illustrates my thoughts about the cost question, which is basically getting lower in price. Lower purchase price allows more of these platforms to be made available, more opportunities for scientists to get their instruments to altitude. Lower operating cost allows more use of the aircraft, which both increases the reliability—in the sense of learning what the issues are—addressing them, also in terms of demonstrating a reliable operation of UAVs which should help with some of the cost issues, for example, insurance.

## UAV Experience - Specific Comments and Issues



### Development of UAVs continues

#### Cost

- Relatively low purchase price allows more UAVs to be built, increasing the number of platforms available.
- Relatively low operating cost allows more use of aircraft by thinly funded science programs.

#### Weather capability

- Flight in icing conditions

#### Operation in airspace system

- Limitations on operations - flight in clouds
- Chase plane requirement
- Equipment requirements (lights, transponder, communications, FTS)

#### Payload integration issues

- Environments/environmental control
- Weight, volume
- Ground compatibility testing
- Remote operation of payload
- Standard interfaces (mechanical, power, data)

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These are some more specific comments and issues that occurred to me. The development of UAVs continues. That was intended to be a coded way of saying that these aircraft are not yet as reliable as fully developed, piloted, certificated aircraft. They are at the front end of the development process. A lot has been done, but more needs to be done. I'm sure it will be done.

But one shouldn't put one's payload on this aircraft with the expectation that it's going to be as reliable as a 737 that somebody flew in here today. That's not quite the case yet. So more development, I think, is appropriate there.

I put cost as a bullet with not a lot of elaboration. At this point it's difficult to characterize the cost of UAVs versus piloted aircraft because they're in much different states of development. But I think this is an issue. Insurance is clearly a concern in terms of per hour cost that may often be the dominant cost of operating UAVs at this point. Again, additional reliable use of UAVs will help address the insurance cost issue as well. The weather capability—I highlighted the icing conditions as one issue. Cross-winds, other factors really are something that need to be addressed, will be addressed. It's just early enough in the development phase that not all these have been fully chased to the ground.

Operation in national airspace system—we've been able to work a number of our flights in general use airspace. We've been able to address the issues and use them satisfactorily. More could be done. The goal would be that the UAV will operate just like any other aircraft without requiring a chase airplane, without any other special restrictions on its use. It will take more work to get there, but I think that should be the goal. In terms of payload integration, I don't really have any lessons learned to offer here—other than to point out that these are numerous issues one needs to be worried about in putting a payload on the UAV. We've found, for example, that these are all workable problems. But the environments, the aircraft in general do not have pressurized or inherently heated payload compartments. You need to think about conditioning your instruments—developing them such that they can survive in other than a shirtsleeve environment—maybe a little harsher environment then, characterized by low pressure and perhaps lower

temperatures than you would see in a laboratory-like environment. Weight and volume—of course, you'd always like to have more weight. You'd always like to have more volume. You'd always like to have more electrical power available. Again, it's just a factor to keep in mind. Those are somewhat limited in most of these aircraft. So when you're developing an instrument, think in terms of miniaturizing and making it light, minimizing its power requirements as much as possible. We make it a practice to try and do ground compatibility testing before we commit to a flight. This is an important step in developing and integrating the payload. Also, keep in mind that many of the instruments are designed with the idea in mind of an operator able to access the instrument directly and control its operation. These need to be remotely controlled instruments, which may effect the way you approach the design of the instrument itself. A final bullet here was just a point that when we started the ARM-UAV Program we had a noble goal of encouraging the use of standard interfaces for data, power, size, volume, and so forth. The reality is that many of these instruments were already developed for other purposes and were adapted for UAV use. Some of the instruments were so far along in their development process it wasn't possible for us to direct them into this standard interface. But I still think that's a worthwhile goal, and one that as a community both the UAV providers and the users of UAV services should think about, trying to work towards more standard interfaces here.

**For Additional Information about ARM-UAV** 

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**Please visit our web site at:**

[armuav.atmos.colostate.edu](http://armuav.atmos.colostate.edu)

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If you would like additional information about the ARM-UAV Program, this is the address of our website. There is contact information there, you can get in touch with myself and other people on the program to get more information about instruments or other aspects of the program.

Steve Wegener: Well, as you can see, ERAST UAVs are ready for business. We really can do UAV science, some of it certainly with restrictions. But we're crawling up that curve and we're making a lot of progress. And as we heard earlier in the day, this has really happened over the last five years. We've really come a long way.

Let's start out with questions.

Question: I'm Steve Walter from JPL. First of all, the airborne program right now is oversubscribed in terms of the demand for the airplanes. That's going to get worse with the increase in requirements for Cal/Val activities and science missions. What is NASA going to do to provide additional platforms to try to alleviate some of those problems?

Cheryl Yuhas: What we would propose to alleviate the problem is to see what sort of cooperative programs we have with other agencies and with universities in which we can get access to the aircraft with the capabilities we need on a parttime basis. For example, with NSF we trade hours on their C-130 with ours on our WB-57, which is a cooperative aircraft itself. We borrow it from another organization at NASA.

Question: Where do you see the instrument development being funded for UAVs?

Cheryl Yuhas: The instrument development for UAVs would be funded through the sensor development and technology program such as the Instrument Incubator Program (IIP).

Question: But the Instrument Incubator Program last time discouraged UAV instruments because of the risk involved.

Cheryl Yuhas: Those are the programs we have for developing new—

Question: Two comments. One is, my perception is that there's a lack of coordination here between the Earth Science Technology Office and the ERAST Program in terms of making programs available for UAVs. The other comment is that in a downsizing environment, loss of an instrument could mean layoffs for the people involved. And so not only does the Earth Science Technology Office say that proposing for UAVs for IIP is risky, it's also career-wise risky right now in NASA.

Cheryl Yuhas: Well, basically, one of the objectives of the position that I'm currently acting in is to increase the coordination between the Technology Program in the Earth Science Division and what we're doing. And seeing problems like this and getting feedback from the different developers is the way I deal with it. I would go to the Technology Office and work with the NRAs as they come out to bring them all in line.

Steve Wegener: It is a very real problem. I think as we demonstrate reliability with missions like this, the IIP folks will begin to take notice a bit more and, hopefully, be supporting it. We've got to push it. We realize it's a problem. And we're trying to do what we can.

Question: If you could give us a ballpark estimate for the total integrated cost of what we saw in that video, taking into account the different contributions from the different agencies, [that would help a lot].

William Bolton: We normally think of one of these deployments costing about \$1 to \$1.2 million. That's the aggregated cost. In this case, the costs were split between the ERAST Program and DOE-ARM UAV Program.

Question: And the second question was for Estelle. I was hoping to get a peek at her last chart. So if I can remember the question. How much money does Mike have set aside for this sort of stuff or whatever it was that you...

Estelle Condon: He has no money set aside for it. This [slide not available] shows the upper atmosphere research budgets from 1992 to present. The blue is the actual budget. The red is if there had been at least three percent inflation. So you can see there's a huge, huge difference in buying power in '99 from '92. That has a direct impact on the ability to develop new instruments. It also makes people far more

conservative about putting an expensive instrument on a UAV platform that may or may not have the reliability of our manned aircraft. Because you can't replace it with a budget scenario that looks like this.

Robert Schiffer: Let me just add that that's true of virtually every other research program; we see that we've been operating under, at best, a kind of fixed envelope. There's no room for compensating for inflation. So the buying power essentially is tailing off. That's a fact of life. One of the things that we have done is try and leverage activities with Code R and its atmospheric effects of aviation program—UAV-ARM—where we can bring budgets together to help do some of these missions.

Question: Given this picture then, and the fact that the ERAST budget plan has another \$80 million in it over the next five years, what are the plans for continued coordination between say UARP and ERAST?

Estelle Condon: I can't answer that directly. All I can tell you is that Mike [Dr. Michael J. Kurylo, Head of the Upper Atmospheric Research Project in the Office of Earth Science at NASA Headquarters] has leveraged his money in every way possible. He worked with the atmospheric effects of aircraft hand-in-glove for the ten years of the program. I think if an opportunity presents itself to work with the ERAST Program, he would never back away from that.

Question: George Getz, Navy, China Lake. I hate to bring this up, but I would suggest that an air-to-air collision incident would be disastrous to the UAV Program. And I was wondering if there is any kind of safety of flight or stringent reliability requirement that's being laid on the programs.

Steve Wegener: Actually I can not answer the question. It's a valid question, and that's why we're restricting our flights right now to test ranges like PMRF and Dryden. The investment between now and FY 02 is in developing our next generation UAV. We are requiring that vehicle to operate in unrestricted airspace. So we are trying to make that investment and force that to happen. Because we agree with that sensitivity of operating in the general aviation airspace—in unrestricted airspace. I don't have a specific answer for you. But I can tell you we're very sensitive and concerned about those operations.

John Sharkey: We are working with the FAA and others to evolve those kinds of criteria and have those fairly uniformly apply to UAVs, not only within ERAST but across the industry.

Steve Wegener: If I could just amplify John Sharkey's comments a little, there is extensive technical and operational review that goes on before any of the flights that you see taking place here in any of the ARM or ERAST flight operations. I mean, it's done under the full regime of the NASA procedures here at Dryden and coordinated with the Air Force and the FAA, and so on.

Question: I'm Robbie Hood with Marshall Space Flight Center. Another question I had is probably a longer-term goal of the whole program. As we foresee these aircraft going up and staying up for extended periods of time collecting lots of data, especially for six months at a time, the data archival issues are going to approach those of a satellite mission. Are plans being made to incorporate that, or is it assumed that these will be PI-driven data archives and that're going to come out of the general funding?

Steve Wegener: Well, it seems real clear that that's going to have to be a PI issue. And right now there're no plans made for that kind of long-term archival [effort]. You can even get huge amounts of data off of short missions with some of these if you were to be flying multi-spectral sensors. So that's really right now a PI issue. That type of concern is very real and I think needs to be addressed. But right now, the focus is on flying missions that are certainly much shorter than that. Your concern is noted, and I've heard it before.

Question: Pete Conway from Marshall. Is the UAV community working with the instrument developers to try to identify specific instruments that would work better in the environments that are inherent to the UAV?

Steve Wegener: Right now, the mode of this has been kind of driven by the science questions driving measurement strategies that would develop payloads. Those payloads need to be evolved clearly in coordination with the UAV for interface issues, environmental issues, and so on.

Question: Yes. The reason I asked the question is that I got the feeling from earlier discussions that you're building UAVs initially but, the long term approach has got to be the instruments, more than the UAV. Because you have to work with the microelectronics organizations and companies in order to get instruments in these aircraft.

Steve Wegener: And the instruments are driven by the science questions. And so all of that's got to be coordinated, all the way from the science question through to the platform, and developed in concert, depending on what the mission is.

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